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Commentary on corrosion at bimetallic contacts and its alleviation

Commentaire sur la corrosion aux contacts bimétalliques et sa réduction

Kommentar zur Korrosion an bimetallischen Kontakten und deren Verminderung

BSI STANDARDS

Commentary on corrosion at bimetallic contacts and its alleviation

Section one. General

1. Scope

This document gives guidance to designers, to help them to avoid situations in which corrosion may arise from the interaction of different metals and alloys at bimetallic contacts.

It comprises two sections. Section one gives details of conditions affecting corrosion at bimetallic contacts and methods of alleviating it, and section two consists of annotated tables indicating the degree of additional corrosion likely to occur at bimetallic contacts exposed to atmospheric and aqueous environments.

The document does not deal with other environments, such as those encountered in chemical engineering, where the effects may be different, and it does not refer to situations where contact between certain metals, even below their melting point, may lead to some interpenetration and consequential embrittlement.

The metals and alloys are identified in the tables by their generally accepted descriptions, but it will be appreciated that many variations in composition and condition are found in practice. For further information on the behaviour of particular alloys, reference should be made to the appropriate development association, trade association, manufacturer or supplier. In the case of defence stores, further information may be obtained from the appropriate branch of the Ministry of Defence.

2. Conditions affecting corrosion at bimetallic contacts

2.1 Introduction. When two different metals are in electrical contact and are also bridged by water containing an electrolyte (e.g. water containing salt, acid, combustion product), current flows through the solution from the anodic or baser metal to the cathodic or nobler metal. As a result, the nobler metal tends to be protected, but the baser metal may suffer greater corrosion. In the past, schedules of electrode potentials have been published which have been of value in drawing the attention of designers to the dangers of bimetallic corrosion.
Such schedules can, however, be misleading, since the potential difference between metals, although it is the prime driving force of the corrosion current, is not a reliable guide to the rate and form of corrosion suffered at any particular contact. In particular, statements claiming that specific differences of potential are safe or unsafe, are unreliable.

An apparent exception to the necessity for the two metals to be in electrical contact for corrosion to occur is when a more noble metal corrodes slightly and dissolves in water that subsequently flows over a less noble metal. The more noble metal may then deposit on the less noble metal, thus forming a true bimetallic contact. For example, copper can dissolve very slightly in some natural waters and may then deposit on low alloy or carbon steels, aluminium or zinc.

Bimetallic corrosion may also be experienced when two dissimilar metals, not in direct contact, are nevertheless connected electrically.

2.2 The electrolyte and its effects. The severity of bimetallic corrosion is dependent on the conductivity of the electrolyte solution. For example, other things being equal, sea water, being a highly conducting solution, gives rise to more severe bimetallic corrosion than most fresh waters, which are generally of lower conductivity.

Rain water, in a clean rural atmosphere, has a low conductivity, but in polluted atmospheres, it can dissolve fuel combustion products, or sea-salts in marine environments, to give a water of moderately high conductivity.

Similarly, a film of moisture condensed from the air can, like rain-water, dissolve contaminants and provide conditions for bimetallic corrosion to take place.
In addition, contaminants already present on the metal surface, such as finger prints or residues of processing solutions, may absorb moisture from the atmosphere which, although humid, has not actually reached the dewpoint.

Bimetallic corrosion is more severe under immersed conditions than in the atmosphere. In the latter, the severity of attack is influenced to a large extent by the time that the bimetallic contact remains wet, which is dependent upon many factors such as the presence of spray, the degree of sheltering from direct rainfall, and the retention of moisture in crevices. The effectiveness of drainage and the speed of evaporation are particularly relevant factors. The areas of the metals that remain wet in the vicinity of the contact can also have an important effect (see 2.4). In atmospheric conditions, bimetallic corrosion is usually localized in the vicinity of the line of contact.

Whilst the recommendations in this document are valid for most natural environments, they are no substitute for particular experience of behaviour in a specific environment under consideration. For example, some substances which may be present merely as traces in the environment can have a profound effect on behaviour at bimetallic contacts. The corrosion at the junction may be accelerated or reduced substantially and it is even possible for 'normal' behaviour to be reversed.

Additional corrosion may occur at crevices where the supply of oxygen at interfaces between joined components is limited. This is not bimetallic corrosion, but its effects at bimetallic joints can be as detrimental as true bimetallic corrosion. Cases where the crevice effect may be significant are noted in the tables.

2.3 Condition of the metal or alloy. In a corrosive environment, a metal or alloy can behave slightly differently depending on its condition, e.g. its state of heat treatment or the amount of cold work it has undergone. Hence an article of one material, but with different parts in different physical conditions, might be expected to show quasi-bimetallic corrosion. Such effects have been ignored in compiling the tables.

2.4 Area relationships. The risk of corrosion under immersed conditions at a bimetallic junction is greatest if the area of the more noble metal is large compared with the area of the less noble metal.

2.5 Metallic coatings. (See also **3.2.**) Many metals, e.g. chromium, tin, nickel, cadmium, zinc, aluminium, are commonly used as protective coatings on another metal. Some of these coatings are more noble and some less noble than the substrate. Both kinds protect initially by excluding the environment from the substrate and should therefore be as free from pores as possible. If the substrate is exposed, as at pores, cut edges or where the coating has corroded, a bimetallic cell is created. If the coating is more noble, corrosion of the substrate may then be increased. If the coating is less noble (sacrificial), the substrate may be protected until the coating is locally consumed or until the corrosion is restrained by the formation of scale or inhibitive corrosion products.

3. Prevention of bimetallic corrosion

3.1 Insulation. The basic principle underlying the prevention of corrosion arising from dissimilar metals in contact is to prevent the flow of the corrosion currents. This may be achieved:

(a) by insulating the dissimilar metals from each other, i.e. breaking the metallic path, or

(b) by preventing the formation of a continuous bridge of electrolyte solution between the two metals, i.e. breaking the electrolytic path.

Under immersed conditions, (a) may be possible if insulation is not precluded by a need for electrical bonding. For example, a base metal nut and bolt should be fitted with an insulating bush and washers where it passes through a nobler plate. Complete insulation is essential in such a case and therefore the bush is vital. Method (b) may be effected by the application of paint or plastics coating to the immersed parts of the metal. Where protection is sought by this means and it is impracticable to coat both metals, then it is preferable to coat the more noble one.

3.2 Metallic coatings. (See also **2.5.**) Significant bimetallic corrosion may be avoided by applying to one of the metals of the couple, a coating of the other, or (more commonly) a coating of another metal chosen for its compatibility, or sometimes by coating both metals with a single suitable metal.

The effectiveness of these methods depends on the continuing integrity of the coating, although this is less important if the coating is applied to the more noble metal; this is therefore the practice to be adopted wherever practicable. If the coating has to be applied to the less noble metal, any pores or breaks in the coating caused by damage or by corrosion will concentrate the attack at the relatively small bared areas of the less noble metal. It is especially important in these cases that the coating is given protection, e.g. by passivation treatment, paints, jointing compounds.

An example of a compatible metal applied to a more noble metal of a couple is the use in the aircraft industry of cadmium coatings on stainless steel in contact with aluminium alloys. Similarly, brass in contact with aluminium alloys can be prevented from damaging the latter by coating the brass with zinc or cadmium.

The complete coating of an assembly with a single suitable metal is especially appropriate to smaller components composed of two or more different metals or alloys.

3.3 Non-metallic coatings (excluding paint). Non-metallic coatings are useful in particular cases, e.g. anodizing of certain aluminium alloys.

3.4 Jointing compounds. Jointing compounds should be able to exclude water, should not dry or crack and should not be corrosive. If formulated with an adequate corrosion inhibitor, they may suffice for moderate conditions, but subsequent painting is also advisable. Jointing compounds also protect against crevice corrosion.

3.5 Paints and other organic coatings. The application to the assembled joint of an overall paint system, suitable for the specific environment, is effective. The combination of a jointing compound and subsequent painting is better than either alone. Thick, water-resisting plastics or mastic coatings, where they can be used, are useful.

3.6 Cathodic protection. As indicated in **2.1**, a metal may be protected or have its rate of corrosion reduced by being coupled to a more corrodible metal. This is commonly referred to as sacrificial protection and is one form of cathodic protection. Similar protection may be achieved by applying an e.m.f. in the appropriate direction from a suitable anode. Bimetallic corrosion of two dissimilar metals in contact may sometimes be prevented by joining them electrically either to an anode and impressing an e.m.f. on the system, or by coupling them electrically to a third metal which is sufficiently corrodible to protect them both. In all cases, the metals and the anode must be immersed in the electrolyte solution and be in electrical contact with each other. It is advisable to seek informed advice when applying cathodic protection methods.

Section two. Tables

4. Tabulated data on the behaviour of bimetallic couples

4.1 Description of tables. The data are set out in a series of tables, each table being devoted to the behaviour of one metal or alloy, or in some cases similar groups of metals or alloys, when coupled to other metals or to carbon. Explanatory notes accompany each table.

It is emphasized that the ratings for behaviour given in the tables refer to the *additional* corrosion caused by bimetallic effects; a favourable rating does not imply that no protection is necessary.

The severity of the additional corrosion that can be caused by bimetallic effects is related to the environment and to other effects such as relative areas (as indicated in 2.2 and 2.4). In the tables, five broad classes of environment, three atmospheric and two immersed, are listed.

4.2 Guidance in the use of the tables. To find the data on the behaviour of a couple, the behaviour against each other of the two metals or alloys comprising the couple has to be sought. Thus, in every case *two tables* have to be consulted, together with the accompanying notes. Failure to do this could result in the choice of a couple in which, under the conditions of service envisaged, one member of the couple could be sacrificially corroded at an unacceptable rate.

In selecting the appropriate column for an atmospheric environment, it has to be remembered that there may be localities within a region that have 'microclimates' vastly different from the environmental characteristics of the region as a whole. A region designated 'rural' may have local environments more closely resembling an industrial atmosphere at sites close to and downwind of factories. Similarly, a site near the sea, but close to shore installations may, with appropriate prevailing winds, have the characteristics of an industrial rather than a marine atmosphere. Because of this and other factors (briefly referred to in 2.2) that result in localized conditions of increased severity, it is advisable to study the precise conditions prevailing at the actual site before deciding on the appropriate environment column.

4.3 Metals for which there are no individual tables. The metals and alloys (a) to (e) listed below do not in general suffer additional corrosion by contact with other metals nor with each other, and for this reason have no tables of their own. They can, however, affect the performance of other metals with which they are in contact, and are therefore included in the 'metal in contact' column of the tables of all the other metals. Carbon behaves in a similar manner.

(a) Gold
(b) Platinum
(c) Rhodium
(d) Silver
(e) Titanium and titanium alloys

The following metals, (f) to (k), also have no tables of their own, neither are they included in the 'metal in contact' columns, since little is known of their behaviour in contact with other metals or with each other.

(f) Molybdenum
(g) Niobium
(h) Tantalum
(j) Tungsten
(k) Zirconium

No individual tables are included for hard solders, brazing filler metals or weld filler metals, since these materials cover wide ranges of composition. Some general guidance may be obtained by reference to the tables showing alloys closest in composition to the alloys concerned, but for more specific information, the manufacturer of the particular alloy should be consulted.

4.4 Further information. If circumstances arise which are not obviously covered by the information given in the two appropriate tables, further advice should be obtained from the appropriate development association, trade association, manufacturer or supplier. In the case of defence stores, further information should be obtained from the appropriate branch of the Ministry of Defence. Advice on corrosion matters may also be obtained from the Corrosion Advice Bureau of the British Steel Corporation and the Metals Users Consultancy Service of the BNF Metals Technology Centre.

Table 1. Additional corrosion of aluminium and aluminium alloys resulting from contact with other metals or carbon

See also table	Metal in contact	Environment*				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
	Aluminium and aluminium alloys†					
2	Aluminium bronzes and silicon bronzes	1	3	3	3	3
3	Brasses including high tensile (HT) brass (manganese bronze)	1	3	3	3	3
4	Cadmium	0	0	0	(0)	0
	Carbon	1	2	3	(3)	3
5	Cast irons	0	1	2	1	3
6	Cast iron (austenitic)	1	(2)	(3)	(2)	(3)
7	Chromium	1	1	2	(2)	(3)
8	Copper	1	3	3	3	3
9	Cupro-nickels	1	3	3	3	3
	Gold	(1)	(3)	(3)	(3)	(3)
10	Gunmetals, phosphor bronzes and tin bronzes	1	3	3	3	3
11	Lead	0	0	0 to 3	(2)	3
12	Magnesium and magnesium alloys‡	0	1	2	1	2
13	Nickel	(1)	2	3	(2)	(3)
14	Nickel-copper alloys	1	3	3	3	3
15	Nickel-chromium-iron alloys	(1)	(2)	(3)	(2)	(3)
16	Nickel-chromium-molybdenum alloys	(1)	(2)	(3)	(2)	(3)
17	Nickel silvers	(1)	(3)	(3)	(3)	(3)
	Platinum	(1)	(3)	(3)	(3)	(3)
	Rhodium	(1)	(3)	(3)	(3)	(3)
	Silver	(1)	(3)	(3)	(3)	(3)
	Solders (hard) §	1	1 to 2	1 to 3	(3)	2 to 3
18	Solders (soft) ‖	1	2	3	(2)	3
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	1	2	2	3
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	1	2	2	3
21	Steels (carbon and low alloy)	1	1	3	2	3
22	Tin	(1)	(2)	(3)	(2)	(3)
	Titanium and titanium alloys	0	1	2	2	3
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Aluminium and aluminium alloys will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Aluminium and aluminium alloys will suffer slight or moderate corrosion which may be tolerable in some circumstances.

2 Aluminium and aluminium alloys may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Aluminium and aluminium alloys may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Rating 3 does not necessarily mean that the combination of metals is not used in practice, but it does mean that precautions should be taken to avoid a corrosion path between the two metals. For example, a wrought iron or steel anchor chain/cable is successfully used on an aluminium alloy hull in sea water, the corrosion path being avoided by a simple insulated coupling between the two metals. Aluminium is also successfully used in contact with steel under marine environments if the steel is coated with metallic aluminium.

†Crevice corrosion can occur between contacting aluminium surfaces, particularly under marine or industrial exposure conditions. This can be countered by a coat of zinc chromate primer on the contacting surfaces.

‡Magnesium is anodic to aluminium, but under marine conditions the strongly alkaline corrosion products can cause corrosion of the aluminium.

§Solders containing heavy metals such as copper or silver can cause corrosion of aluminium in the presence of a good electrolyte. Optimum corrosion resistance is obtained with a zinc-aluminium solder and optimum joint efficiency is obtained with pure aluminium, or aluminium-manganese alloys. Brazing, sometimes referred to as hard soldering, can utilize an aluminium-silicon brazing rod, and so minimize the occurrence of galvanic corrosion. Residues of halide-containing fluxes should be thoroughly removed from the joint.

‖ Solders containing lead, and to a lesser extent tin, can cause corrosion of aluminium in the presence of a good electrolyte. A tin-zinc solder is preferred to a tin-lead solder. Residues of halide containing fluxes can provide the good electrolyte and such fluxes should be thoroughly removed from the joint.

Table 2. Additonal corrosion of aluminium bronzes and silicon bronzes resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed*	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
	Aluminium bronzes and silicon bronzes					
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon†	0	1	1	2	3
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
7	Chromium	0	0	1	1	1
8	Copper	0	0	0	0	0
9	Cupro-nickels	0	0	0	0	1
	Gold	1	1	2	2	3
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	0	0	0
11	Lead	0	0	0	0	0
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	0
14	Nichel-copper alloys	0	0	1	1	1
15	Nickel-chromium-iron alloys	0	0	0	1	1
16	Nickel-chromium-molybdenum alloys	0	0	0	1	1
17	Nickel silvers	0	0	0	0	0
	Platinum	1	1	2	2	3
	Rhodium	1	1	2	2	3
	Silver	0	1	1	1	2
	Solders (hard)	0	0	0	0	0
18	Solders (soft)	0	0	0	0	0
19 302 316	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	1	1
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	1	1
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0‡	0‡
	Titanium and titanium alloys	0	0	0	1	2
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Aluminium bronzes and silicon bronzes will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Aluminium bronzes and silicon bronzes will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Aluminium bronzes and silicon bronzes may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Aluminium bronzes and silicon bronzes may suffer severe additional corrosion and the contact should be avoided.

General note. The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*In immersed conditions, the effects will depend on a number of factors including relative areas of the two metals, the velocity of water flow and the degree of aeration.

†Carbon residues formed during manufacture or during fabrication can cause serious corrosion in many environments.

‡A coating of tin on copper and copper alloys may, over a period of time, depending on coating thickness and service temperature, become transformed by diffusion into a coating of copper-tin intermetallic compound. This alloy coating will be less likely to suffer additional corrosion, but it may promote additional corrosion of metals in contact with it, including any exposed substrate metal.

Table 3. Additional corrosion of brasses including high tensile (HT) brasses (manganese bronze)* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed†	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes‡	0	0	0	0	1
	Brasses including high tensile (HT) brass (manganese bronze)					
4	Cadmium	0	0	0	0	0
	Carbon §	0	1	1	2	3
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	1
7	Chromium	0	0	1	1	1
8	Copper ‡	0	0	0	0	0
9	Cupro-nickels ‡	0	0	0	0	1
	Gold	1	1	2	2	3
10	Gunmetals, phosphor bronzes and tin bronzes ‡	0	0	0	0	1
11	Lead	0	0	0	0	1
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	1
14	Nickel-copper alloys	0	0	1	1	2
15	Nickel-chromium-iron alloys	0	0	0	1	1
16	Nickel-chromium-molybdenum alloys	0	0	0	1	1
17	Nickel silvers	0	0	0	0	0
	Platinum	1	1	2	2	3
	Rhodium	1	1	2	2	3
	Silver	0	1	1	1	2
	Solders (hard)	0	0	0	0	0
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	1	1
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	1	1
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0 ‖	0 ‖
	Titanium and titanium alloys	0	0	0	1	2
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Brasses will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Brasses will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Brasses may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Brasses may suffer severe additional corrosion and the contact should be avoided.

General note. The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Manganese bronzes are more correctly termed high tensile brasses.

†In immersed conditions, the effects will depend on a number of factors including relative areas of the two metals, the velocity of water flow and the degree of aeration.

‡Brasses subject to dezincification and used in waters in which this occurs will suffer additional corrosion rating '1'.

§Carbon residues formed during manufacture or during fabrication can cause serious corrosion in many environments.

‖ A coating of tin on copper and copper alloys may, over a period of time, depending on coating thickness and service temperature, become transformed by diffusion into a coating of copper-tin intermetallic compound. This alloy coating will be less likely to suffer additional corrosion, but it may promote additional corrosion of metals in contact with it, including any exposed substrate metal.

Table 4. Additional corrosion of cadmium* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0 to 1	0 to 1	1	1 to 2
2	Aluminium bronzes and silicon bronzes	0 to 1	1	1 to 2	1 to 2	2 to 3
3	Brasses including high tensile (HT) brass (manganese bronze)	0 to 1	1	0 to 2	1 to 2	2 to 3
	Cadmium					
	Carbon	0 to 1	1	1 to 2	0 to 2	2 to 3
5	Cast irons	0 to 1	1	1 to 2	1 to 2	2 to 3
6	Cast iron (austenitic)	0 to 1	1	1 to 2	1 to 2	1 to 3
7	Chromium	0 to 1	1 to 2	1 to 2	1 to 2	2 to 3
8	Copper	0 to 1	1 to 2	1 to 2	1 to 2	2 to 3
9	Cupro-nickels	0 to 1	0 to 1	1 to 2	1 to 2	2 to 3
	Gold	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
10	Gunmetals, phosphor bronzes and tin bronzes	0 to 1	1	1 to 2	1 to 2	2 to 3
11	Lead	0	0 to 1	0 to 1	0 to 2	(0 to 2)
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0 to 1	1	1 to 2	1 to 2	2 to 3
14	Nickel-copper alloys	0 to 1	1	1 to 2	1 to 2	2 to 3
15	Nickel-chromium-iron alloys	(0 to 1)	(1)	(1 to 2)	(1 to 2)	(1 to 3)
16	Nickel-chromium-molybdenum alloys	(0 to 1)	(1)	(1 to 2)	(1 to 2)	(1 to 3)
17	Nickel silvers	0 to 1	1	1 to 2	1 to 2	1 to 3
	Platinum	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
	Rhodium	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
	Silver	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
	Solders (hard)	0 to 1	1	1 to 2	1 to 2	2 to 3
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0 to 1	0 to 1	0 to 1	0 to 2	1 to 2
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0 to 1	0 to 1	0 to 1	0 to 2	1 to 2
21	Steels (carbon and low alloy)	0 to 1	1	1 to 2	1 to 2	1 to 2
22	Tin	0	0 to 1	1	1	1 to 2
	Titanium and titanium alloys	(0 to 1)	(1)	(1 to 2)	(0 to 2)	(1 to 3)
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Cadmium will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Cadmium will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Cadmium may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Cadmium may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Cadmium is frequently used as a sacrificial coating on other metals. Additional corrosion will reduce the life of the coating.

Table 5. Additional corrosion of cast irons resulting from contact with other metals or carbon

		Environment				
		Atmospheric			Immersed	
See also table	Metal in contact	Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0 to 1	1	1	1	2
3	Brasses including high tensile (HT) brass (manganese bronze)	0 to 1	1 to 2	1 to 2	2	3
4	Cadmium	0	0	0	0	0
	Carbon	(0 to 1)	(1 to 2)	(1 to 2)	(2)	(3)
	Cast irons*					
6	Cast iron (austenitic)	0	0 to 1	1	1 to 2	2
7	Chromium	0	0 to 1	1	1 to 2	2
8	Copper	0 to 1	1 to 2	1 to 2	2	3
9	Cupro-nickels	0 to 1	1 to 2	1 to 2	2	3
	Gold	0 to 1	1 to 2	1 to 2	2	3
10	Gunmetals, phosphor bronzes and tin bronzes	0 to 1	1 to 2	1 to 2	2	3
11	Lead	0	0 to 1	0 to 1	1 to 2	2
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0 to 1	1 to 2	1 to 2	2	3
14	Nickel-copper alloys	0 to 1	1 to 2	1 to 2	2	3
15	Nickel-chromium-iron alloys	0 to 1	1 to 2	1 to 2	2	2 to 3
16	Nickel-chromium-molybdenum alloys	0 to 1	1 to 2	1 to 2	2	3
17	Nickel silvers	0 to 1	1 to 2	1 to 2	2	3
	Platinum	0 to 1	1 to 2	1 to 2	2	3
	Rhodium	0 to 1	1 to 2	1 to 2	2	3
	Silver	0 to 1	1 to 2	1 to 2	2	3
	Solders (hard)	0 to 1	1 to 2	1 to 2	2	2 to 3
18	Solders (soft)	0 to 1	1 to 2	1 to 2	2	2 to 3
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0 to 1	1 to 2	1 to 2	2	3
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	(0 to 1)	(1 to 2)	(1 to 2)	(2)	(3)
21	Steels (carbon and low alloy)	0	0	0	0	0 to 1
22	Tin	0	0	1	1	0 to 2
	Titanium and titanium alloys	0 to 1	0 to 1	1 to 2	2	3
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Cast irons will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Cast irons will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Cast irons may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Cast irons may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*No risk of galvanic corrosion exists unless one of the cast iron components has a layer of graphitic corrosion residue.

Table 6. Additional corrosion of cast iron (austenitic)* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	(1)	0	1 to 2†
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	(1)	0	1
4	Cadmium	0	0	0	0	0
	Carbon	(1)	(1)	(2)	1	2 to 3†
5	Cast irons	0	0	0	0	0
	Cast iron (austenitic)					
7	Chromium	0	0	(1)	0	(1)
8	Copper	0	0	(1)	(0 to 1)	1 to 2†
9	Cupro-nickels	0	0	(1)	(0 to 1)	1 to 2
	Gold	(1)	(1)	(2)	1	2 to 3†
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	(1)	(0 to 1)	1 to 2
11	Lead	0	0	(1)	0	1 to 2†
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	(1)	0	1 to 2
14	Nickel-copper alloys	0	0	(1)	0	1 to 2†
15	Nickel-chromium-iron alloys	0	0	(1 to 2)	0	1 to 2†
16	Nickel-chromium-molybdenum alloys	(0 to 1)	(0 to 1)	(1 to 2)	1	1 to 2†
17	Nickel silvers	0	0	(1)	0	1 to 2†
	Platinum	(1)	(1)	(2)	1	2 to 3†
	Rhodium	(1)	(1)	(2)	1	2 to 3†
	Silver	(1)	(1)	(2)	1	2 to 3†
	Solders (hard)	0	(0)	(1)	(0)	1 to 2†
18	Solders (soft)	0	(0)	(1)	(0)	1 to 2†
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	(1)	(0)	1 to 2†
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	(1)	(0)	0 to 2†
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	(0)	(1)	(0)	1 to 2
	Titanium and titanium alloys	0	(1)	(1)	(1)	1 to 2†
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Austenitic cast iron will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Austenitic cast iron will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Austenitic cast iron may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Austenitic cast iron may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Austenitic cast iron is also referred to as nickel cast iron.

†The higher value of the range shown applies when the area of nickel cast iron (austenitic) is small in relation to the area of the second alloy forming the couple.

Table 7. Additional corrosion of chromium* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	0	0	0
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon	–	–	–	–	–
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
	Chromium					
8	Copper	0	0	0	0	0
9	Cupro-nickels	0	0	0	0	0
	Gold	–	–	–	–	–
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	0	0	0
11	Lead	–	–	–	–	–
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	0
14	Nickel-copper alloys	0	0	0	0	0
15	Nickel-chromium-iron alloys	0	0	0	0	0
16	Nickel-chromium-molybdenum alloys	0	0	0	0	0
17	Nickel silvers	0	0	0	0	0
	Platinum	–	–	–	–	–
	Rhodium	–	–	–	–	–
	Silver	–	–	–	–	–
	Solders (hard)	–	–	–	–	–
18	Solders (soft)	–	–	–	–	–
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	0	0
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	0	0
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	–	–	–	–	–
	Titanium and titanium alloys	–	–	–	–	–
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Chromium will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Chromium will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Chromium may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Chromium may suffer severe additional corrosion and the contact should be avoided.

General notes. Dashes indicate that no evidence is available and no general guidance can be given.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Data relates to chromium as plated in deposits of 75 µm to 125 µm thickness.

Table 8. Additional corrosion of copper resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed*	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	0	0	0
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon†	0	1	1	2	3
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
7	Chromium	0	0	1	1	1
	Copper					
9	Cupro-nickels	0	0	0	0	1
	Gold	1	1	2	2	3
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	0	0	0
11	Lead	0	0	0	0	1
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	0
14	Nickel-copper alloys	0	0	1	1	2
15	Nickel-chromium-iron alloys	0	0	0	1	0 to 1
16	Nickel-chromium-molybdenum alloys	0	0	0	1	0 to 2‡
17	Nickel silvers	0	0	0	0	0
	Platinum	1	1	2	2	3
	Rhodium	1	1	2	2	3
	Silver	0	1	1	1	2
	Solders (hard)	0	0	0	0	0
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	0 to 2‡	0 to 2‡
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	1	0 to 1
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0§	0§
	Titanium and titanium alloys	0	0	0	1	2
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Copper will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Copper will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Copper may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Copper may suffer severe additional corrosion and the contact should be avoided.

General note. The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*In immersed conditions, the effects will depend on a number of factors including relative areas of the two metals, the velocity of water flow and the degree of aeration. With increasing velocity of water flow, copper tends to become less noble whilst nickel-chromium-iron, nickel-chromium-molybdenum alloys and stainless steels tend to become more noble.

†Carbon residues formed during manufacture or during fabrication can cause serious corrosion in many environments.

‡The higher value of the range shown applies when the area of copper is small in relation to the area of the second alloy forming the couple or when the velocity of sea water flow is high.

§ A coating of tin on copper and copper alloys may, over a period of time, depending on coating thickness and service temperature, become transformed by diffusion into a coating of copper-tin intermetallic compound. This alloy coating will be less likely to suffer additional corrosion, but it may promote additional corrosion of metals in contact with it, including any exposed substrate metal.

Table 9. Additional corrosion of cupro-nickels resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed*	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	0	0	0
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon†	0	1	1	2	3
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
7	Chromium	0	0	0	1	1
8	Copper	0	0	0	0	0
	Cupro-nickels ‡					
	Gold	1	1	2	2	3
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	0	0	0
11	Lead	0	0	0	0	0
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	0
14	Nickel-copper alloys	0	0	0	0	1
15	Nickel-chromium-iron alloys	0	0	0	0	0
16	Nickel-chromium-molybdenum alloys	0	0	0	0 to 2	0 to 2 §
17	Nickel silvers	0	0	0	0	0
	Platinum	1	1	2	2	3
	Rhodium	1	1	2	2	3
	Silver	0	1	1	0	1
	Solders (hard) ‖	0	0	0	0	0
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	0 to 2	0 to 2 §
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	0	0
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0	0
	Titanium and titanium alloys	0	0	0	0	1
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Cupro-nickels will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Cupro-nickels will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Cupro-nickels may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Cupro-nickels may suffer severe additional corrosion and the contact should be avoided.

General note. The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*In immersed conditions, the effects will depend on a number of factors including relative areas of the two metals, the velocity of water flow and the degree of aeration.

†Carbon residues formed during manufacture or during fabrication can cause serious corrosion in many environments.

‡90/10 cupro-nickel is less noble than the 70/30 alloy. It may suffer slight additional corrosion in contact with the 70/30 alloy and may suffer slightly more than the 70/30 alloy in contact with other metals.

§The higher value of the range shown applies when the area of the second alloy forming the couple is large in relation to the area of the cupro-nickel and when the velocity of sea water flow is high.

‖Brazing alloys containing phosphorus should not be used with cupro-nickel.

Table 10. Additional corrosion of gunmetals, phosphor bronzes and tin bronzes resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed*	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	0	0	0
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon†	0	1	1	2	3
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
7	Chromium	0	0	1	1	1
8	Copper	0	0	0	0	0
9	Cupro-nickels	0	0	0	0	1
	Gold	1‡	1‡	2‡	2	3
	Gunmetals, phosphor bronzes and tin bronzes					
11	Lead	0	0	0	0	0
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	0
14	Nickel-copper alloys	0	0	1	1	1
15	Nickel-chromium-iron alloys	0	0	0	0	0
16	Nickel-chromium-molybdenum alloys	0	0	0	0 to 1	0 to 2
17	Nickel silvers	0	0	0	0	0
	Platinum	1‡	1‡	2‡	2	3
	Rhodium	1‡	1‡	2‡	2	3
	Silver	0‡	1‡	1‡	1	2
	Solders (hard)	0	0	0	0	0
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	0 to 1	0 to 2§
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	0	0
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0‖	0‖
	Titanium and titanium alloys	0	0	0	1	2
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Gunmetals, phosphor bronzes and tin bronzes will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Gunmetals, phosphor bronzes and tin bronzes will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Gunmetals, phosphor bronzes and tin bronzes may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Gunmetals, phosphor bronzes and tin bronzes may suffer severe additional corrosion and the contact should be avoided.

General note. The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*In immersed conditions, the effects will depend on a number of factors including relative areas of the two metals, the velocity of water flow and the degree of aeration.

†Carbon residues formed during manufacture or during fabrication can cause serious corrosion in many environments.

‡These ratings refer to outdoor exposure. The combinations are used in electrical contacts indoors (including inboard in ships) and no corrosion is usually encountered.

§The higher value of the range shown applies when the area of the second alloy forming the couple is large in relation to the area of the gunmetal and when the velocity of sea water flow is high.

‖ A coating of tin on copper and copper alloys may, over a period of time, depending on coating thickness and service temperature, become transformed by diffusion into a coating of copper-tin intermetallic compound. This alloy coating will be less likely to suffer additional corrosion, but it may promote additional corrosion of metals in contact with it including any exposed substrate metal.

Table 11. Additional corrosion of lead* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine†	Fresh water‡	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	1	0 to 1	1
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0 to 1	0 to 1	1
4	Cadmium	0	0	0	0	0
	Carbon	0 to 1	0 to 1	0 to 2	0 to 2	0 to 2
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	–	–	(0)	(0)	0
7	Chromium	(0)	(0)	(0 to 1)	(0 to 1)	(0 to 1)
8	Copper	0	0	1	0 to 1	1
9	Cupro-nickels	0	0	1	0 to 1	1
	Gold	–	–	(0 to 1)	(0 to 1)	(0 to 1)
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	0 to 1	0 to 1	1
	Lead §					
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0 to 1	0 to 1	0 to 1
14	Nickel-copper alloys	0	0	0 to 1	0 to 1	0 to 1
15	Nickel-chromium-iron alloys	–	–	–	–	0 to 1
16	Nickel-chromium-molybdenum alloys	–	–	–	–	0 to 1
17	Nickel silvers	0	0	0 to 1	0 to 1	1
	Platinum	–	–	–	–	–
	Rhodium	–	–	–	–	–
	Silver	(0)	(0)	(0 to 1)	(0 to 1)	(0 to 1)
	Solders (hard)	–	–	–	–	–
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	(0)	(0)	(0 to 1)	0 to 1	0 to 1
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	(0)	(0)	(0 to 1)	0 to 1	0 to 1
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0	0
	Titanium and titanium alloys	–	–	–	–	–
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Lead will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Lead will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Lead may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Lead may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

Dashes indicate that no evidence is available and no general guidance can be given.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*The information relates to massive lead, with or without small quantities of alloying additions, and to coatings substantially composed of lead on other metals.

†Where two figures are given, the higher figure applies in the presence of spray.

‡Effect is variable. Bicarbonates, sulphates and silicates in concentrations usually present in supply waters minimize the effect. Rise of temperature and aeration may enhance the effect.

§Lead may be subject to crevice corrosion. Such corrosion may also occur at contacts with other metals which do not otherwise stimulate corrosion.

Table 12. Additional corrosion of magnesium and magnesium alloys* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric		Immersed†‡		
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys§	1	1‖	2‖	1	3‖
2	Aluminium bronzes and silicon bronzes	2	2	3	2	3
3	Brasses including high tensile (HT) brass (manganese bronze)	2	2	3	2	3
4	Cadmium¶	0	1	1	1	2
	Carbon	(2)	2	3	2	3
5	Cast irons	1	2	3	2	3
6	Cast iron (austenitic)	(1)	(2)	(3)	(2)	(3)
7	Chromium	1	2	3	2	3
8	Copper	2	2	3	2	3
9	Cupro-nickels	(2)	(2)	(3)	(2)	(3)
	Gold	(2)	(2)	(3)	(2)	(3)
10	Gunmetals, phosphor bronzes and tin bronzes	(2)	(2)	(3)	(2)	(3)
11	Lead	(1)	(1)	(2)	–	–
	Magnesium and magnesium alloys**					
13	Nickel	2	2	3	2	3
14	Nickel-copper alloys	(2)	(2)	(3)	(2)	(3)
15	Nickel-chromium-iron alloys	(2)	(2)	(3)	(2)	(3)
16	Nickel-chromium-molybdenum alloys	(2)	(2)	(3)	(2)	(3)
17	Nickel silvers	(2)	(2)	(3)	(2)	(3)
	Platinum	(2)	(2)	(3)	(2)	(3)
	Rhodium	(2)	(2)	(3)	(2)	(3)
	Silver	(2)	(2)	(3)	(2)	(3)
	Solders (hard)	(2)	(2)	(3)	(2)	(3)
18	Solders (soft)	(1)††	(1)††	(2)	–	–
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	1	2	3	2	3
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	1	2	3	2	3
21	Steels (carbon and low alloy)	1	2	3	2	3
22	Tin	1	1	2	1	2
	Titanium and titanium alloys	1	2	3	2	3
23	Zinc and zinc base alloys¶	0	1	1	1	2

Key

0 Magnesium and magnesium alloys will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Magnesium and magnesium alloys will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Magnesium and magnesium alloys may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Magnesium and magnesium alloys may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

Dashes indicate that no evidence is available and no general guidance can be given.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Magnesium is the least noble of all structural metals and is corroded galvanically by contact with all other structural metals in the presence of an electrolyte. Cadmium and zinc are the only safe contacts in other than mild environments.

†Magnesium alloys are not normally used in immersed conditions irrespective of galvanic contacts.

‡In conducting waters, the relative areas of the magnesium and the contact metal would have some influence.

§Aluminium-copper alloys accelerate the corrosion of magnesium alloys more than other aluminium base materials.

‖With the couple magnesium-aluminium, corrosion of the more noble metal aluminium can also occur, caused by alkali liberated at its surface by the galvanic corrosion. See table 1 on aluminium and aluminium alloys.

¶If the cadmium or zinc are plated coatings on more noble metals, the life of the contact will depend on the thickness of the plate and its durability in the environment.

**Magnesium alloys do not suffer from crevice corrosion (as a result of exclusion of air), but corrosion at crevices may be more rapid than elsewhere owing to the accumulation of dirt and slow evaporation of water.

††Flux residues containing chloride provide a local electrolyte which could promote galvanic attack.

Table 13. Additional corrosion of nickel resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	0 to 1	0	0 to 2*
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon	(0 to 1)	(0 to 1)	(0 to 2)	(0 to 1)	2 to 3*
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
7	Chromium	0	0	1	0	(1)
8	Copper	0	0	0 to 1	0	0 to 2*
9	Cupro-nickels	0	0	1	0	0 to 2*
	Gold	1	1	2	1	2 to 3
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	0 to 1	0	0 to 2*
11	Lead	0	0	0	0	0
12	Magnesium and magnesium alloys	0	0	0	0	0
	Nickel					
14	Nickel-copper alloys	0	0	(0 to 2)	0	0 to 2*
15	Nickel-chromium-iron alloys	0	0	(0 to 2)	0	0 to 2*
16	Nickel-chromium-molybdenum alloys	(0 to 1)	(0 to 1)	(0 to 2)	(0 to 1)	0 to 2*
17	Nickel silvers	0	0	0 to 1	0	0 to 1*
	Platinum	(1)	(1)	(1 to 2)	(1)	2 to 3*
	Rhodium	(1)	(1)	(1 to 2)	(1)	2 to 3*
	Silver	(1)	(1)	(1 to 2)	(1)	(2 to 3)
	Solders (hard)	0	0	0	0	0 to 2
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0 to 1	0	1 to 2*
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	0	0
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0	0
	Titanium and titanium alloys	0	0	1	0	1 to 2
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Nickel will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Nickel will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Nickel may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Nickel may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*The higher value of the range shown applies when the area of nickel is small in relation to the area of the second alloy forming the couple.

Table 14. Additional corrosion of nickel-copper alloys resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	0	0	0
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon	0	0	(0 to 1)	0	1 to 2*
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
7	Chromium	0	0	0	0	0 to 1*
8	Copper	0	0	0	0	0
9	Cupro-nickels	0	0	0	0	0
	Gold	0	0	(1)	0	1 to 2*
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	0	0	0
11	Lead	0	0	0	0	0
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	0
	Nickel-copper alloys					
15	Nickel-chromium-iron alloys	0	0	0	0	0
16	Nickel-chromium-molybdenum alloys	0	0	(0 to 1)	0	0 to 2*
17	Nickel silvers	0	0	0	0	0
	Platinum	0	0	(0 to 1)	0	1 to 2*
	Rhodium	0	0	(0 to 1)	0	1 to 2*
	Silver	0	0	(0 to 1)	0	(0 to 2)
	Solders (hard)	0	0	0	0	0
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	0	0 to 1*
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	0	0
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0	0
	Titanium and titanium alloys	0	0	(0 to 1)	0	1 to 2
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Nickel-copper alloys will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Nickel-copper alloys will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Nickel-copper alloys may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Nickel-copper alloys may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*The higher value of the range shown applies when the area of nickel copper alloys is small in relation to the area of the second alloy forming the couple.

Table 15. Additional corrosion of nickel-chromium-iron alloys resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	(0 to 1)	0	0 to 2*
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon	0	0	(1)	(1)	2 to 3*
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
7	Chromium	0	0	0	0	(0 to 1)*
8	Copper	0	0	0	0	0 to 2*
9	Cupro-nickels	0	0	0	0	0 to 2*
	Gold	0	0	(1)	(1)	1 to 2*
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	(0 to 1)	0	0 to 2*
11	Lead	0	0	0	0	0
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	0
14	Nickel-copper alloys	0	0	0	0	0 to 2*
	Nickel-chromium-iron alloys					
16	Nickel-chromium-molybdenum alloys	0	0	0	0	0
17	Nickel silvers	0	0	(0 to 1)	(0 to 1)	(1 to 2)
	Platinum	0	0	(0 to 1)	0	2 to 3*
	Rhodium	0	0	(0 to 1)	(1)	2 to 3*
	Silver	0	0	(0 to 1)	(1)	2 to 3*
	Solders (hard)	0	0	(0 to 1)	0	(1 to 2)
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	(0 to 1)	0 to 2
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	0	0
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0	0
	Titanium and titanium alloys	0	0	(0 to 1)	0	(1 to 2)
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Nickel-chromium-iron alloys will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Nickel-chromium-iron alloys will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Nickel-chromium-iron alloys may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Nickel-chromium-iron alloys may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*The higher value of the range shown applies when the area of nickel-chromium-iron alloy is small in relation to the area of the second alloy forming the couple.

Table 16. Additional corrosion of nickel-chromium-molybdenum alloys resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	0	0	0
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon	0	0	0	0	0 to 2*
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
7	Chromium	0	0	0	0	0
8	Copper	0	0	0	0	0
9	Cupro-nickels	0	0	0	0	0
	Gold	0	0	0	0	0 to 1*
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	0	0	0
11	Lead	0	0	0	0	0
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	0
14	Nickel-copper alloys	0	0	0	0	0
15	Nickel-chromium-iron alloys	0	0	0	0	0
	Nickel-chromium-molybdenum alloys					
17	Nickel silvers	0	0	0	0	0
	Platinum	0	0	0	0	0 to 1*
	Rhodium	0	0	0	0	0 to 1*
	Silver	0	0	0	0	0 to 1*
	Solders (hard)	0	0	0	0	0
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	0	0
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	0	0
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0	0
	Titanium and titanium alloys	0	0	0	0	0
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Nickel-chromium-molybdenum alloys will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Nickel-chromium-molybdenum alloys will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Nickel-chromium-molybdenum alloys may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Nickel-chromium-molybdenum alloys may suffer severe additional corrosion and the contact should be avoided.

General note. The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*The higher value of the range shown applies when the area of nickel-chromium-molybdenum alloy is small in relation to the area of the second alloy forming the couple.

Table 17. Additional corrosion of nickel silvers* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed†	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	0	0	0	0
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0	0	0
4	Cadmium	0	0	0	0	0
	Carbon‡	0	1	1	2	3
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	0	0	0	0	0
7	Chromium	0	0	1	1	1
8	Copper	0	0	0	0	0
9	Cupro-nickels	0	0	0	0	0
	Gold	0 to 1§	0 to 1§	0 to 2§	2	3
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	0	0	1
11	Lead	0	0	0	0	1
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0	0	0	0
14	Nickel-copper alloys	0	0	1	1	2
15	Nickel-chromium-iron alloys	0	0	0	1	0
16	Nickel-chromium-molybdenum alloys	0	0	0	0 to 1	0 to 2‖
	Nickel silvers					
	Platinum	0 to 1§	0 to 1§	0 to 2§	2	3
	Rhodium	0 to 1§	0 to 1§	0 to 2§	2	3
	Silver	0§	0 to 1§	0 to 1§	1	2
	Solders (hard)	0	0	0	0	0
18	Solders (soft)	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0	0	0	0 to 1	0 to 2‖
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0	1	0
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0	0
	Titanium and titanium alloys	0	0	0	1	2
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Nickel silvers will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Nickel silvers will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Nickel silvers may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Nickel silvers may suffer severe additional corrosion and the contact should be avoided.

General note. The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Nickel silver is the generic term for brasses in which a substantial proportion of copper is replaced by nickel.

†In immersed conditions, the effects will depend on a number of factors including relative areas of the two metals, the velocity of water flow and the degree of aeration.

‡Carbon residues formed during manufacture or during fabrication can cause serious corrosion in many environments.

§These ratings refer to outdoor exposure. The combinations are used in electrical contacts indoors (including inboard in ships) and no corrosion is usually encountered.

‖The higher value of the range shown applies when the area of nickel silvers is small in relation to the area of the second alloy forming the couple and when the velocity of sea water flow is high.

Table 18. Additional corrosion of soft solders* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric		Immersed		
		Rural	Industrial/urban	Marine†	Fresh water‡	Sea water
1	Aluminium and aluminium alloys §	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	(0)	(0 to 1)	(1 to 2)	(0 to 1)	(2)
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0	0 to 1	1	1 to 2
4	Cadmium	0	0	0	0	0
	Carbon	(0)	(0 to 1)	(0 to 2)	(0 to 2)	(0 to 2)
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	(0)	(0)	(0)	(0)	0
7	Chromium	(0)	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)
8	Copper	0	0 to 1	1 to 2	0 to 2	1 to 2
9	Cupro-nickels	0	0 to 1	1 to 2	0 to 2	1 to 2
	Gold	(0)	(0 to 1)	(1 to 3)	(1 to 3)	(3)
10	Gunmetals, phosphor bronzes and tin bronzes	0	0	(0 to 1)	1	1 to 2
11	Lead	0	0	0	0	0
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	0 to 1	0 to 2	0 to 2	1 to 2
14	Nickel-copper alloys	0	0 to 1	1 to 2	0 to 2	1 to 2
15	Nickel-chromium-iron alloys	–	–	–	–	0 to 1
16	Nickel-chromium-molybdenum alloys	–	–	–	–	0 to 1
17	Nickel silvers	0	0 to 1	0 to 2	0 to 2	0 to 2
	Platinum	–	–	–	–	–
	Rhodium	–	–	–	–	–
	Silver	–	–	–	–	–
	Solders (hard)	–	–	–	–	–
	Solders (soft)					
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	(0)	(0)	0 to 1	0 to 1	0 to 2
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	(0)	(0)	0 to 1	0 to 1	0 to 2
21	Steels (carbon and low alloy)	0	0	0	0	0
22	Tin	0	0	0	0	0
	Titanium and titanium alloys	–	–	–	–	–
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Soft solders will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Soft solders will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Soft solders may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Soft solders may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

Dashes indicate that no evidence is available and no general guidance can be given.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Information relates mainly to the use of tin-lead solders as jointing materials. In general the behaviour of other tin-lead surfaces such as those of coatings on other metals will be similar, but the consequences of additional corrosion will not be as serious for them as they are with the area ratios existing in soldered joints. The effects on additional corrosion of solder compositions in the range commonly used are usually small. Reference may be made to the tables dealing with tin and with lead for additional information about the extreme ends of the possible composition range. Residue of halide-containing fluxes used in soldering are likely to increase corrosion risks. When strongly corrosive fluxes are used, the joint should be thoroughly cleaned after soldering.

The application of a tin or a tin-lead coating to the second metal is often a suitable means of protection; this has an additional advantage in that the use of corrosive fluxes in soldering may be avoided.

†Where two figures are shown, the higher figure applies in the presence of spray.

‡Effect variable. Bicarbonates, sulphates and silicates, in the concentration usually present in supply waters, minimize effect. Rise of temperature and aeration may enhance effect. The design of joint is also important, a lapped or capillary joint may be satisfactory where an open fillet would be destructively corroded.

§In a joint made with tin-lead solder, although the bulk of the solder is not affected, serious corrosion at the interface between solder and aluminium alloy may occur. A tin-zinc solder is to be preferred.

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Table 19. Additional corrosion of stainless steel (austenitic, with approximately 18 % chromium) resulting from contact with other metals or carbon*

		Environment				
		Atmospheric			Immersed	
See also table	Metal in contact	Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0†	0	(0)	0
2	Aluminium bronzes and silicon bronzes	0	1‡	(0 to 1)†‡	–	0 to 1 §
3	Brasses including high tensile (HT) brass (manganese bronze)	0	1‡	(0 to 1)†‡	–	0 to 1 §
4	Cadmium	0	0	0	(0)	0
	Carbon	–	–	–	–	1 §
5	Cast irons	0†	1†	–	(0)	0
6	Cast iron (austenitic)	–	(0)	–	(0)	0 §
7	Chromium	0	(0)	(0)	(0)	(0)
8	Copper	0	1†‡	(0 to 2)†‡	–	0 to 3 §
9	Cupro-nickels	(0)	1†‡	(0 to 2)†‡	–	0 to 3 §
	Gold	–	–	–	–	–
10	Gunmetals, phosphor bronzes and tin bronzes	(0)	(0)	(0)	(0)	(0 to 1) §
11	Lead	0	–	0	–	0 to 1
12	Magnesium and magnesium alloys	(0)	0	(0)	(0)	0
13	Nickel	–	–	(0)	–	0 §
14	Nickel-copper alloys	0	0 to 1	0 to 1†‡	–	0 to 2 §
15	Nickel-chromium-iron alloys	–	–	–	–	0 to 2 §
16	Nickel-chromium-molybdenum alloys	–	–	–	–	0 to 2 §
17	Nickel silvers	–	–	–	–	0 to 1 §
	Platinum	–	–	–	–	–
	Rhodium	–	–	–	–	–
	Silver	–	–	–	–	–
	Solders hard	–	–	–	–	0 to 1 §
18	Solders soft‖	–	–	–	(0)	0 §
	Stainless steel (austenitic and other grades containing approximately 18 % chromium)					
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0	0	0 to 1	(0)	0 §
21	Steels (carbon and low alloy)	0†	0†	0 to 1†	(0)†	0† §
22	Tin	–	–	–	–	(0 to 1) §
	Titanium and titanium alloys	–	–	–	–	–
23	Zinc and zinc base alloys	0†	0	0	(0)	0

Key

0 Austenitic stainless steels will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Austenitic stainless steels will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Austenitic stainless steels may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Austenitic stainless steels may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

Dashes indicate that no evidence is available and no general guidance can be given.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Crevice corrosion may occur.

†Corrosion products from the metal in contact may be deposited on the stainless steel, at best discolouring the stainless steel and at worst promoting corrosion of the stainless steel under the deposit.

‡Effect will depend on relative areas over which water, e.g. rain or condensation, may be retained.

§ Effect depends on relative areas. If the area of stainless steel is small in relation to that of the coupled metal there may be considerable extra corrosion. If the areas are equal there may be some effect. If the area of stainless steel is relatively large there would not normally be any extra corrosion though pitting may be more likely to occur.

‖Residues of fluxes containing halides used in soldering are likely to increase corrosion rates. When strongly corrosive fluxes are used the joint should be thoroughly cleaned after soldering.

Table 20. Additional corrosion of stainless steel (martensitic, with approximately 13 % chromium) resulting from contact with other metals or carbon*

See also table	Metal in contact	Environment: Atmospheric: Rural	Industrial/urban	Marine	Immersed: Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	(0)	(0 to 1)†‡	(0 to 1)†‡	–	1 to 3§
3	Brasses including high tensile (HT) brass (manganese bronze)	(0)	(0 to 1)†‡	(0 to 1)†‡	–	1 to 3§
4	Cadmium	0	0	0	0	0
	Carbon	–	–	–	–	3§
5	Cast irons	(0)	(0)†	(0)†	0 to 1	0 to 1†§
6	Cast iron (austenitic)	(0)	(0)	(0)	(0)	(0)
7	Chromium	(0)	(0)	(0)	(0)	(0)
8	Copper	–	(0 to 1)†‡	(0 to 1)†‡	–	1 to 3§
9	Cupro-nickels	–	(0 to 1)†‡	(0 to 1)†‡	–	1 to 3§
	Gold	–	–	–	–	–
10	Gunmetals, phosphor bronzes and tin bronzes	(0)	(0)†	(0)†	(0)	1 to 3§
11	Lead	(0)	(0)	(0)	–	1§
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	(0)	(0)	(0)	–	1 to 3§
14	Nickel-copper alloys	(0)	(0 to 1)†‡	(0 to 1)†‡	–	1 to 3§
15	Nickel-chromium-iron alloys	–	–	–	–	1 to 3§
16	Nickel-chromium-molybdenum alloys	–	–	–	–	1 to 3§
17	Nickel silvers	–	–	–	–	1 to 3§
	Platinum	–	–	–	–	–
	Rhodium	–	–	–	–	–
	Silver	–	–	–	–	–
	Solders hard	–	–	–	–	1 to 3§
18	Solders soft‖	–	–	–	–	0 to 2§
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	(0)	(0 to 1)‡	(0 to 1)‡	–	1 to 2§
	Stainless steel (martensitic grades containing approximately 13 % chromium)					
21	Steels (carbon and low alloy)	(0)	(0 to 1)†	(0 to 1)†	(0 to 1)§	(0 to 1)§
22	Tin	–	–	–	–	1§
	Titanium and titanium alloys	–	–	–	–	–
23	Zinc and zinc base alloys	0	0†	0†	0	0

Key

0 Martensitic stainless steels will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Martensitic stainless steels will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Martensitic stainless steels may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Martensitic stainless steels may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

Dashes indicate that no evidence is available and no general guidance can be given.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Crevice corrosion may occur.

†Corrosion products from the metal in contact may be deposited on the stainless steel, at best discolouring the stainless steel and at worst promoting corrosion of the stainless steel under the deposit.

‡Effect will depend on relative areas over which water, e.g. rain or condensation, may be retained.

§Effect depends on relative areas. If the area of stainless steel is small in relation to that of the coupled metal there may be considerable extra corrosion. If the areas are equal there may be some effect. If the area of stainless steel is relatively large there would not normally be any extra corrosion, though pitting may be more likely to occur.

‖Residues of fluxes containing halides used in soldering are likely to increase corrosion rates. When strongly corrosive fluxes are used the joint should be thoroughly cleaned after soldering.

Table 21. Additional corrosion of steels (carbon and low alloy)* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric†			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	2 to 3	2 to 3	3	3	3
3	Brasses including high tensile (HT) brass (manganese bronze)	2 to 3	2 to 3	3	3	3
4	Cadmium	0	0	0	0	0
	Carbon	1 to 2	1 to 3	–	–	3
5	Cast irons	0 to 1	0 to 1	2	0 to 1	0 to 2
6	Cast iron (austenitic)	(0 to 1)	(0 to 1)	(0 to 2)	(1)	1 to 3
7	Chromium	1	1	2	1 to 2	1 to 2
8	Copper	1 to 2	1 to 2	(2 to 3)	3	2 to 3
9	Cupro-nickels	1 to 2	1 to 2	3	3	2 to 3
	Gold	–	–	–	–	–
10	Gunmetals, phosphor bronzes and tin bronzes	1 to 2	1 to 2	3	3	3
11	Lead	0 to 1	0 to 1	0 to 1	0 to 1	1
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	(0 to 1)	1	1 to 2	1 to 2	1 to 3
14	Nickel-copper alloys	(0 to 1)	(1)	(1 to 2)	(1 to 2)	1 to 3
15	Nickel-chromium-iron alloys	(0 to 1)	(1)	(1 to 2)	(1 to 2)	1 to 3
16	Nickel-chromium-molybdenum alloys	(0 to 1)	(1)	(1 to 2)	(1 to 2)	1 to 3
17	Nickel silvers	1	1	1	2	3
	Platinum	–	–	–	–	–
	Rhodium	–	–	–	–	–
	Silver	–	–	–	–	–
	Solders hard	1	1	–	2	2 to 3
18	Solders soft	1	1	1	2 to 3	2 to 3
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	1	–	2 to 3	2	2 to 3
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	1	1	2 to 3	2	2 to 3
	Steels (carbon and low alloy)					
22	Tin	1	1	1	1	1
	Titanium and titanium alloys	–	–	–	–	–
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Carbon and low alloy steels will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Carbon and low alloy steels will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Carbon and low alloy steels may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Carbon and low alloy steels may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

Dashes indicate that no evidence is available and no general guidance can be given.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*The effect will depend on relative areas of the metals in contact. If the area of carbon steel or low alloy steel is equal to that of the metal with which it is in contact, then the effect will be as shown in the table. If the area of the carbon steel or low alloy steel is small in relation to the area of the other metal, then considerable extra corrosion may result. If the area of carbon steel or low alloy steel is large then the effect may not be so marked.

†Under atmospheric conditions other factors, such as area wetted, presence of spray, degree of shelter and crevices, will assume importance.

Table 22. Additional corrosion of tin* resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine†	Fresh water‡	Sea water‡
1	Aluminium and aluminium alloys	0	0	0	0	0
2	Aluminium bronzes and silicon bronzes	0	1	1 to 2§	0 to 1	1 to 2§
3	Brasses including high tensile (HT) brass (manganese bronze)	0	0 to 1	0 to 1	1	1
4	Cadmium	0	0	0	0	0
	Carbon	0	(1)	(2)	(1)	(2)
5	Cast irons	0	0	0	0	0
6	Cast iron (austenitic)	(0)	(0)	(0)	(0)	(0)
7	Chromium	(0)	(1)	(1 to 2)	(1)	(2)
8	Copper	0	1	1 to 2§	1	2§
9	Cupro-nickels	0	1	1 to 2§	1	2§
	Gold	(0)	(1)	(2)	(1)	(2)
10	Gunmetals, phosphor bronzes and tin bronzes	0	0 to 1	0 to 1	1	1
11	Lead	0	0	0	0	0
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0	1	1 to 2§	1	2§
14	Nickel-copper alloys	0	1	1 to 2§	1	2§
15	Nickel-chromium-iron alloys	–	–	–	–	1
16	Nickel-chromium-molybdenum alloys	–	–	–	–	1
17	Nickel silvers	(0)	(1)	(1 to 2)	(1)	(2)
	Platinum	–	–	–	–	–
	Rhodium	–	–	–	–	–
	Silver	(0)	(1)	(2)	1	2
	Solders hard	–	–	–	–	–
18	Solders soft	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	(0)	(0 to 1)	(1 to 2)	1	2
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	(0)	(0 to 1)	(1 to 2)	1	2
21	Steels (carbon and low alloy)	0	0	0	0	0
	Tin‖					
	Titanium and titanium alloys	–	–	–	–	–
23	Zinc and zinc base alloys	0	0	0	0	0

Key

0 Tin will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Tin will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Tin may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Tin may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

Dashes indicate that no evidence is available and no general guidance can be given.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Information relates either to massive tin or to complete tin coatings on other metals. Coatings of tin alloys behave differently: tin-nickel alloy will not usually suffer additional corrosion from any contact, tin-zinc alloy will be affected rather like zinc and tin-lead rather like soft solders. A coating of tin on copper or on copper alloys may become, in a time depending on the coating thickness and service temperature, transformed by diffusion into a coating of copper-tin intermetallic compound. This alloy coating will be less likely than tin to suffer additional corrosion but it may promote additional corrosion of many metals in contact with it including any exposed substrate metal.

†Where two figures are given, the higher figure applies in the presence of spray.

‡Except when the area of tin is small, any additional corrosion is likely to take the form of an increase in the number of points of local attack, many of which may be distant from the contact area. With increased temperature or with waters containing dissolved salts, but depositing little or no scale, the effect may be enhanced.

§A rating of 2 should not be taken to imply that tin is an unsuitable protective coating for the metal.

‖ For the immersed condition, crevice corrosion may occur.

Table 23. Additional corrosion of zinc and zinc base alloys resulting from contact with other metals or carbon

See also table	Metal in contact	Environment				
		Atmospheric			Immersed	
		Rural	Industrial/urban	Marine	Fresh water	Sea water
1	Aluminium and aluminium alloys	0	0 to 1	0 to 1	1	1 to 2
2	Aluminium bronzes and silicon bronzes	0 to 1	1	1 to 2	1 to 2	2 to 3
3	Brasses including high tensile (HT) brass (manganese bronze)	0 to 1	1	0 to 2	1 to 2	2 to 3
4	Cadmium	0	0	0	0	0
	Carbon	0 to 1	1	1 to 2	0 to 2	2 to 3
5	Cast irons	0 to 1	1	1 to 2	1 to 2	2 to 3
6	Cast iron (austenitic)	0 to 1	1	1 to 2	1 to 2	1 to 3
7	Chromium	0 to 1	1 to 2	1 to 2	1 to 2	2 to 3
8	Copper	0 to 1	1 to 2	1 to 2	1 to 2	2 to 3
9	Cupro-nickels	0 to 1	0 to 1	1 to 2	1 to 2	2 to 3
	Gold	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
10	Gunmetals, phosphor bronzes and tin bronzes	0 to 1	1	1 to 2	1 to 2	2 to 3
11	Lead	0	0 to 1	0 to 1	0 to 2	(0 to 2)
12	Magnesium and magnesium alloys	0	0	0	0	0
13	Nickel	0 to 1	1	1 to 2	1 to 2	2 to 3
14	Nickel copper alloys	0 to 1	1	1 to 2	1 to 2	2 to 3
15	Nickel-chromium-iron alloys	(0 to 1)	(1)	(1 to 2)	(1 to 2)	(1 to 3)
16	Nickel-chromium-molybdenum alloys	(0 to 1)	(1)	(1 to 2)	(1 to 2)	(1 to 3)
17	Nickel silvers	0 to 1	1	1 to 2	1 to 2	1 to 3
	Platinum	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
	Rhodium	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
	Silver	(0 to 1)	(1 to 2)	(1 to 2)	(1 to 2)	(2 to 3)
	Solders hard	0 to 1	1	1 to 2	1 to 2	2 to 3
18	Solders soft	0	0	0	0	0
19	Stainless steel (austenitic and other grades containing approximately 18 % chromium)	0 to 1	0 to 1	0 to 1	0 to 2	1 to 2
20	Stainless steel (martensitic grades containing approximately 13 % chromium)	0 to 1	0 to 1	0 to 1	0 to 2	1 to 2
21	Steels (carbon and low alloy)	0 to 1	1	1 to 2	1 to 2	1 to 2
22	Tin	0	0 to 1	1	1	1 to 2
	Titanium and titanium alloys	(0 to 1)	(1)	(1 to 2)	(0 to 2)	(1 to 3)
	Zinc and zinc base alloys					

Key

0 Zinc and zinc base alloys will suffer either no additional corrosion, or at the most only very slight additional corrosion, usually tolerable in service.

1 Zinc and zinc base alloys will suffer slight or moderate additional corrosion which may be tolerable in some circumstances.

2 Zinc and zinc base alloys may suffer fairly severe additional corrosion and protective measures will usually be necessary.

3 Zinc and zinc base alloys may suffer severe additional corrosion and the contact should be avoided.

General notes. Ratings in brackets are based on very limited evidence and hence are less certain than other values shown.

The table is in terms of *additional corrosion* and the symbol 0 should not be taken to imply that the metals in contact need no protection under all conditions of exposure.

*Zinc is frequently used as a sacrificial coating on other metals. Additional corrosion will reduce the life of the coating.