

Introduction

Any corrosion of metals used for external cladding may affect the appearance and eventually structural integrity of the facade. This Technical Note presents the basic theory of corrosion, indicates the conditions under which it may occur and the means by which its occurrence and consequences may be minimised.

Corrosion mechanism

Most metals are only found in nature as minerals in which the metal is combined with other elements. Production of the pure metal requires processes in which energy is expended and the resulting metal is not in an inherently stable form. Given time it will react with chemicals in the environment to revert to stable compounds. This process is known as corrosion.

Direct reaction between metals and dry air results in the formation of an oxide film on the surface. As the film grows it prevents contact between the metal and air thus preventing further reaction. The destructive corrosion of metals in the natural environment normally occurs by an aqueous electrochemical mechanism.

When a metal is suspended in water some of the metal atoms dissolve to form ions and the metal develops an electrical potential as a result of the presence of electrons left behind. Different metals in the same solution will have different solubilities and generate different potentials. If they are connected by an external circuit an electric current will flow; in effect a battery will be created. Electrons will flow through the external circuit from the more negatively charged electrode (known as the anode) to the more positively charged electrode (known as the cathode). At the anode the metal will continue to go into solution to replace the lost electrons and maintain the potential. The excess electrons at the cathode may be used up by the formation of

hydroxyl ions from dissolved air and water although other reactions can occur in some circumstances. In the solution, the metal ions can combine with the hydroxyl ions to form the metal hydroxide, which can react with further dissolved oxygen to form the oxide.

The same process can occur on a single piece of metal in water, with potential differences generated by slightly different environmental conditions or slightly different properties of different grains in the metal structure.

This process is used for beneficial purposes in batteries but is also the basic mechanism of metal corrosion. Corrosion protection involves interfering with this process in order to retain the component's appearance and mechanical properties.

Although both oxygen and water are required for electrochemical corrosion, air with a relative humidity greater than 70% contains sufficient moisture to facilitate the corrosion of steel. Corrosion may occur at lower relative humidities if hygroscopic salts are present. A potential difference is also required for corrosion to occur. The potential difference may result from different metals in contact, heterogeneity within a single metal, differences in environmental conditions or differences in stress level. The rate of corrosion will depend on the availability of water and oxygen, the magnitude of the potential difference, the relative sizes of the anode and cathode and the presence of chemicals in the water. Substances, including sulphur compounds and sodium chloride can accelerate the reaction by increasing the conductivity of the electrolyte (e.g. water) and breaking down protective oxide films. Thus corrosion rates are relatively low in clean rural environments but are much higher in industrial atmospheres polluted with acidic sulphur dioxide, or in marine environments where chloride ions are present.

Types of corrosion

The effects of corrosion on a metal can vary from a slight surface discolouration to deep pitting, depending on the type of metal and cause of the corrosion. Corrosion can be classified according to the manner in which it is manifest. Uniform corrosion will occur on unprotected metals subject to uniform exposure. Other types of corrosion tend to start at defects or discontinuities in the protective coating and/or at localised areas of increased exposure/wetness.

Uniform corrosion

Uniform corrosion occurs with equivalent intensity over the entire exposed surface. It is probably the most tolerable form of corrosion since it can be relatively easy to predict and can be allowed for in design by providing an additional sacrificial thickness of metal to allow for loss of section over the life of the component. Familiar examples of uniform corrosion include the general rusting of steel and iron based products and the tarnishing of brass window/door hardware.

All metals used in cladding are potentially subject to uniform corrosion but many, including copper, aluminium and stainless steel, form a tightly bound layer of corrosion product which protects the metal surface from continued attack.

Steel and zinc are subject to ongoing corrosion. Uniform corrosion normally results in an unacceptable rate of decay of unprotected external steel. The rate of corrosion of zinc is very much slower than for steel and zinc may be used without further protection and is commonly used to protect steel.

When lead is exposed to normal atmospheric conditions and rainwater it forms an insoluble protective film however in some conditions, where access to carbon dioxide is limited, the corrosion products are soluble and do not provide protection. An example is condensation on the underside of lead sheet. The risk of condensation can be reduced by designing in accordance with BS 5250 and BS 6229.

Galvanic or bi-metallic corrosion

Galvanic (or bi-metallic) corrosion can be particularly severe and often arises at design details where two metals or alloys having different compositions are electrically coupled while exposed to an electrolyte (e.g. water), as described above.

Different metals in solution will have characteristic potentials allowing metals to be placed in order in the galvanic series (Table 1). When placed in contact, the more anodic metal will corrode leaving the more cathodic metal protected. For example in the case of zinc and steel, the anodic zinc will corrode preferentially to the cathodic steel.

Increasingly active (anodic)	Magnesium
	Zinc
	Aluminium
	Mild steel
	Cast iron
	Stainless steels ¹
	Lead
	Brasses
	Copper alloys
	Stainless steel ²
Increasingly passive (cathodic)	Titanium

Note

1. active state - oxide film disrupted/steel exposed
2. passive state - oxide film intact

Table 1 Cladding metals in the electrochemical series

The rate of galvanic attack depends on:

- The difference in electrical potential of the dissimilar metals (the further apart the metals are in the electrochemical series, the greater is the difference in electrode potential and the more aggressive is the attack on the anode),
- The relative anode-to-cathode surface areas that are exposed to the electrolyte (for a

given cathode area, a smaller anode will corrode more rapidly than a larger one),

- The electrolyte (galvanic corrosion is more serious with soft water and with oxygen starvation).

Thus:

- when iron is in contact with copper, the iron is anodic and corrodes at an accelerated rate whilst the copper is protected; however
- when iron is in contact with zinc, the iron is cathodic and protected, whilst the zinc is anodic and corrodes - this principle is exploited in galvanised steel.

Because of the difference in electrical potential, neither copper nor brass should be used in contact with zinc or zinc alloy coated steels because the galvanic reaction can cause the coating to fail rapidly, especially in polluted atmospheres. Contact between copper and aluminium should also be avoided.

A number of measures may be taken to significantly reduce the effects of galvanic corrosion, including:

- Electrically isolate dissimilar metals from each other;
- Avoid an unfavourable anode-cathode surface area ratio by using an anode area as large as possible;
- Ensure moisture is unlikely to accumulate between dissimilar metals over long periods;
- If coupling of dissimilar metals is unavoidable, choose two that are close together in the galvanic series.

Further guidance on the effects of different combinations of metals is given in PD 6484.

Crevice corrosion

Crevice corrosion occurs in crevices and recesses, or under deposits of dirt or corrosion products, where there is localised depletion of dissolved oxygen. Such conditions can initiate

corrosion of some normally resistant metals (e.g. aluminium and stainless steel) by preventing the formation of the natural protective oxide film. Crevice corrosion can be particularly damaging as it is both localised and likely to occur for relatively long periods as by its nature it takes place at locations that do not dry out rapidly.

Surfaces located below projections are not rain-washed, enabling dirt to accumulate and moisture to be retained at the metal surface, underneath which crevice corrosion can begin. Water can also become trapped at many details and interfaces, for example:

- Between lap joints of sheeting, or between sheets and support rails,
- Between bolted plates and underneath bolt heads,
- Where sheets project into gutters,
- Within small welding imperfections or furrows across the surface of polished metal panels.

Crevice corrosion may be prevented by using non-absorbent gaskets, by removing accumulated deposits frequently and avoiding details that trap water.

Pitting corrosion

Pitting corrosion is another form of very localised corrosion in which small anodic areas in contact with large cathodic areas corrode to form pits or holes. They ordinarily penetrate from the top of a horizontal surface downwards in a nearly vertical direction. A pit may be initiated by a localised surface defect such as a scratch or a slight variation in material composition.

In steel it is an extremely insidious type of corrosion, often going undetected as the volume of corrosion product is small. In aluminium the volume of corrosion product is very much greater than the volume of the pit. The corrosion reaction can therefore be inhibited by self-sealing of the pit.

Filiform corrosion

Filiform corrosion is the growth of thread-like strands or filaments of corrosion that develop beneath coatings. The first evidence of filiform corrosion was found in the aeronautical industry and only after 1980 was it detected in architectural metalwork. It can occur on steel but is of more concern in relation to organically coated aluminium.

Filiform corrosion originates in areas less protected or unprotected by the coating such as pores, scratches, cut edges, rims or surfaces where the coating thickness is thin, and in general those parts where water may accumulate. It only occurs in atmospheres with a high humidity and is more likely to occur in marine zones.

Filiform corrosion may be prevented by a high standard of pre-treatment and coating application, careful detailing to ensure free drainage of water and careful handling of panels.

Factors affecting corrosion

Mortar/concrete

Mortar and concrete are highly alkaline although this alkalinity may be lost by reaction with carbon dioxide in the air in a process known as carbonation. Aluminium, zinc and lead all react with concrete; conversely, iron relies upon the alkalinity of concrete to protect it from corrosion whilst copper is unaffected. The protection of steel by concrete is fundamental to the durability of reinforced concrete.

Aluminium reacts vigorously with wet concrete to produce hydrogen, but is not usually severely attacked by contact with set mortar or concrete. Zinc is not so severely attacked by cement products as aluminium but reacts in a similar manner by giving off hydrogen gas.

Concrete and mortars made from Portland cement or lime can initiate a slow corrosive attack on lead in the presence of moisture. In situations where drying out and carbonation of the free lime in wet concrete or mortar is likely to be slow, lead should be protected with a thick

coat of bitumen paint. Lead flashings turned into masonry joints or chases in concrete not more than 40mm wide are not generally considered to need any protection because here carbonation of free lime is rapid reducing the risk of attack.

When lead cladding, roof coverings and weatherings are applied to concrete surfaces, a sealing coat of hard-drying bitumen paint on the concrete together with an underlay gives adequate protection during the drying out period.

Timber (including preservatives)

Some timbers, particularly western red cedar, oak, sweet chestnut and Douglas fir, contain organic acids which can attack metals including copper, zinc, aluminium and lead. Some timber preservatives, notably copper chrome arsenate, also contain chemicals that can attack metals. The resulting corrosion of fixings embedded in timber can cause breakdown of the timber and loss of holding power of the fixings (nail sickness).

The moisture content of the timber affects the rate of corrosion of the embedded metal and there is a low risk of corrosion if the moisture content of the wood is kept below 20%. Where the moisture content of the wood may exceed 20% corrosion resistant metals should be used for embedded fixings. The choice of metal will depend on the life required and generally increases from galvanised steel through aluminium and copper to stainless steel.

Aluminium and lead sheet can be protected with bituminous paint where they are in contact with run-off from new oak and cedar. The chemicals in the timber will leach out during the first few years. Copper cannot be protected by bituminous paint and should not be exposed to run-off from cedar shingles.

Sealants

Acids, which are exuded during the curing of certain sealants, may cause corrosion of some metals, for example corrosion of lead by acid-cure silicones. The corrosion may only result in the formation of an oxide deposit, but this can be

unsightly. More serious problems may be encountered if acid-cure silicones are used in contact with galvanised steel as the galvanising may be damaged, facilitating corrosion of the substrate.

The compatibility of sealants with metal substrates should always be checked with the sealant manufacturer. Site substitution of a specified sealant with a cheaper alternative should be avoided.

Bitumen

When exposed to ultra violet radiation, bitumen can form highly acidic compounds which if washed onto copper can lead to corrosion. Protecting bitumen from light and water will avoid this problem as will ensuring that run-off from areas of bitumen does not come in contact with copper components.

Temperature

Like most chemical reactions, corrosion will occur at a faster rate as the temperature increases. Where the temperature is greater than 70°C steel may corrode preferentially to zinc.

Algae, moss and lichen

Algae, moss and lichens may produce organic acids, which can attack aluminium, copper, lead and zinc.

Pollution

Industrial pollution increases the rate of general corrosion of steel and zinc. For example the life of a zinc coating in a polluted atmosphere is likely to be about half that in a non-polluted atmosphere.

Copper and lead are not significantly affected by normal levels of pollution although industrial processes producing acetic acid can lead to attack of lead and copper which may be affected by very high levels of sulfur.

Pollution can lead to pitting of aluminium although this may be self-limiting due to the isolating effect of the corrosion products.

Corrosion of all commonly used grades of stainless steel may occur in polluted, marine or chlorinated environments. Grades containing higher quantities of alloying elements have greater resistance to corrosion. In certain circumstances, corrosion may be reduced by regular washing to remove contamination.

The above discussion relates to general atmospheric corrosion. Most metals will be attacked by very severe conditions such as direct contact with flue gasses.

Salt

Exposure to chloride in marine atmospheres, swimming pools or from road de-icing salts is a major cause of corrosion. Chloride may increase the risk of corrosion by breaking down protective oxide films and the rate of corrosion may be increased due to the increased electrical conductivity of the water.

The effects on different metals are generally as described for pollution above.

Stainless steel can corrode when in contact with aluminium in the presence of chloride.

Corrosion protection

Selection of material/composition

The most common and easiest way of preventing corrosion is through the judicious selection of materials, once the corrosion environment has been characterised. However, it is not always feasible to use the material that offers the optimum corrosion resistance and sometimes another alloy and/or some other measure must be used.

Copper, aluminium, lead, and stainless steel have good resistance to corrosion and do not generally require protection provided the factors affecting corrosion discussed above are avoided. Although zinc corrodes when exposed to normal external conditions, the rate of corrosion is slow and a 200 micron thickness can be expected to last 20 to 40 years depending on the level of pollution. Where a longer life is required additional protection can be provided. Plain

carbon steel normally requires protection against corrosion.

Organic coatings

Organic coatings can be applied on site or under factory conditions and create a physical barrier to the corrosive elements. They must maintain a high degree of adhesion to the metal substrate through careful surface pre-treatment and will have a finite life requiring periodic maintenance. Some coatings (e.g. polyester powder coatings) do not provide protection against corrosion of steel and steel substrates and should therefore be pre-treated (e.g. galvanised) before application of such finishes. Coatings are discussed in greater detail in Technical Note 25 *Selection of applied finishes for metals*.

Metal coatings

The performance of a metal coating will depend on whether it is anodic or cathodic to the base metal. A cathodic coating (for example copper on steel) will only protect the base metal by forming a barrier. If there are defects in the coating, rapid local corrosion of the base metal may occur. An anodic coating (for example zinc on steel) will act as a barrier but if there are small defects it will continue to provide protection by corroding preferentially to the base metal as a result of galvanic action.

The most commonly used metal coating is zinc on steel which may be achieved by a number of processes including hot dip galvanising, zinc plating and sherardizing. These processes are described in Technical Note 22 *Cladding metals I – ferrous metals*. Aluminium coating of steel and chromium plating of steel and brass are also used. Chromium plating of steel is an example of a cathodic coating.

Cathodic protection

One of the most effective means of preventing corrosion is cathodic protection, which can in some situations completely stop corrosion. Cathodic protection simply involves supplying electrons, from an external source, to the metal to be protected, making it a cathode. The electrons may be supplied by a sacrificial anode or a low voltage power source. Cathodic

protection is being increasingly used for remedial work on reinforced concrete structures but is unlikely to be appropriate in most cladding situations.

Design

Since the longer the period of wetness the greater the corrosion, it is important that structures should be designed as far as possible to shed rather than trap water and allow complete drainage. Prevention of dirt build up by allowing rain-washing of exposed surfaces will also help to prevent corrosion. Design to prevent condensation and ventilation to aid drying of condensation or penetrating water will also reduce the risk of corrosion.

Local extreme conditions can have a severe, adverse effect on the durability of metals. The strength of the prevailing wind and the regularity of its direction, as well as humidity and the duration of exposure affect the rate of corrosion. For example, severe corrosion can occur when a metal is partly exposed but sheltered, such as under the eaves or canopy of a building. This is particularly true in coastal and severely polluted environments where aggressive salts can lodge themselves in areas that are not washed by rainwater, but where moisture is present due to condensation.

Maintenance

The risk of corrosion can be reduced by regular maintenance. This should include:

- repair or replacement of protective coatings,
- cleaning metal surfaces (particularly in the case of aluminium and stainless steel),
- maintenance of drainage systems,
- maintenance of seals

Summary

This Technical Note has described the types of corrosion that can potentially occur with metal

cladding/roofing panels and associated metalwork. Means of preventing or delaying the onset of corrosion have also been identified, including material selection, material protection, and the design of details.

References and Bibliography

BS 5250, 1995, *Code of practice for control of condensation in buildings*, British Standards Institution.

BS 6229, 1982, *Code of practice for flat roofs with continuously supported coverings*, British Standards Institution.

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