How metals interact in the built environment

Metals and alloys are key components of our houses. Some are lightweight, making them easy to transport and work with. Others have been created to be particularly durable even in aggressive environments. They are not all compatible with each other, however. Poor design or building decisions can result in premature failure.

THE MOST COMMONLY used metals in New Zealand building are steel, aluminium, copper and zinc.

Steel comes in many forms:

- **Mild steel** is an alloy of iron and carbon with small additions of other elements such as manganese and silicon. Mild steel is much more vulnerable to corrosion since its corrosion products provide very limited protection to the underlying substrate when exposed to adverse environments. For example, mild steel fasteners are particularly vulnerable to corrosion in timber with copper-bearing preservatives.
- **Galvanized steel** has a zinc coating that provides significantly enhanced corrosion protection to the steel (zinc is more active and therefore corrodes in preference to the steel). Hot-dip galvanizing gives better protection than other types of application of zinc coating to steel (such as electroplating and mechanical plating). Caution is required when galvanized steel and copper are in direct contact.
- **Stainless steels** contain a minimum 11% chromium and a maximum 1.2% carbon. A chromium-rich passive film can form on the surface spontaneously to reduce further corrosion. Grade 304 and grade 316 are two austenitic stainless steels commonly used in New Zealand buildings. Grade 304 contains 18–20% chromium and 8.0–10.5% nickel. Grade 316 includes 2–3% molybdenum and a slightly higher nickel content of 10–14%, therefore demonstrating a higher resistance to localised corrosion (pitting) when exposed to marine environments. Caution is required when stainless steel is in direct contact with aluminium or zinc.
- **Weathering steels** are a group of steels that exhibit increased resistance to atmospheric corrosion compared to other steels in favourable atmospheric environments. They have very small quantities of copper, chromium, nickel, phosphorus, silicon and/or manganese as alloying elements. Carbon content is typically less than 0.2%.
- **55% aluminium-zinc alloy-coated steel** is very widely used as roof and wall claddings in New Zealand. It has enhanced atmospheric corrosion resistance in rural, industrial and marine environments when compared with hot-dip galvanized zinc-coated steel. Caution is required when used with copper and stainless steel in some environments.

Aluminium is a lightweight metal approximately one-third of the weight of steel. It is widely used in façades, roofs, walls, windows and doors. Aluminium tends to develop a thin passive film on its surface, therefore showing a good corrosion resistance in most natural environments. Corrosion of aluminium typically takes the form of pitting rather than a uniform surface change. Caution is required when aluminium is in direct contact with stainless steel or copper.

Copper generally has high corrosion resistance when exposed to the atmosphere. It is commonly used in buildings as a cladding and flashing material and for gutters and downpipes. Caution is required when copper is in direct contact with aluminium, mild steel or zinc.

Zinc – in addition to its use protecting steel, two standard zinc products are the pure metal (99.995%) and its alloy with small additions of titanium and copper as roofs and façades. Caution is required when zinc is in direct contact with stainless steel or copper.

Galvanic corrosion

One of the key processes that can damage metals in direct contact is galvanic corrosion. This takes place when noble (cathodic) and less noble (anodic) metals (Table 1) are in direct contact in the presence of electrolytes such as marine salts, geothermal sulphur-containing compounds or industrial acid fumes dissolved in water. The least noble metal corrodes at the contact point, and there is partial or complete protection of the most noble metal (Figure 1). The different electrical potentials of different metals are the main driving force for galvanic corrosion.

Building systems that have many metal components such as claddings and HVAC (heating, ventilation and air conditioning) systems are at particular risk of galvanic corrosion. Too often, these systems have been designed with dissimilar metal contacts, increasing the risk of early corrosion, decreasing performance and shortening their service life.

The intensity of galvanic corrosion is partly related to the ratio of areas of the metals in electrical contact. When a noble metal with a large area is coupled to a less noble metal with a small area, galvanic action will cause much more severe corrosion of the less noble metal. The reverse situation where the noble metal has a small area produces little galvanic current. This explains why stainless steel fasteners in aluminium sheets or window frames are normally considered safe if there is no heavy deposition of salt particles.

Table 1. The galvanic series with common metals and alloys listed according to their corrosion potential in seawater.

Graphite	[0.2 → 0.29 V]
Platinum [Pt]	[0.22 → 0.25 V]
AISI 316 [Passive]	[−0.1 → 0 V]
AISI 304 [Passive]	[−0.1 → −0.05 V]
Lead [Pb]	[−0.25 → −0.19 V]
AISI 430 [Passive]	[−0.28 → −0.2 V]
AISI 410 [Passive]	[−0.35 → −0.26 V]
Silicon bronze	[−0.29 → −0.26 V]
Copper	[−0.37 → −0.3 V]
Brass	[−0.4 → −0.3 V]
Mild steel	[−0.63 → −0.57 V]
Aluminium [Al]	[−1.0 → −0.76 V]
Zinc [Zn]	[−1.03 → −0.98 V]
Magnesium [Mg]	[−1.63 → −1.6 V]

Noble [least active]

A lot of construction rules or guidelines around the use of metals are based on avoiding or reducing galvanic corrosion. For example, Acceptable Solution E2/AS1 Table 21 *Compatibility of materials in contact* says that copper and brass are not compatible with aluminium, galvanized steel or zinc. The reason is clear when you look at their places in the galvanic series in Table 1.

Corrosion can also occur when water that has passed over a more noble metal flows over a less noble metal. For example, aluminium may corrode if water passes over lead then aluminium. This is possible on older buildings that still have lead flashings or lead in soft-edge ridge caps.

Metal fasteners in timbers treated with copper-based preservatives

Galvanic corrosion also plays a key role in the deterioration of metal fastenings or fixings in timber with copper-based treatments, specifically the water-based treatments chromated copper arsenate (CCA), copper azole and alkaline or ammoniacal copper quaternary.

Copper azole and alkaline copper quaternary are used for H3.1, H3.2, H4 and H5 treatment levels. They have higher levels of copper retention in the timber than CCA at the same treatment level and therefore are more corrosive to steel and galvanized steel fixings.

BRANZ has researched the problem of metal fastener corrosion in timber with copper-based treatments, including conducting multi-year field trials. Field tests with above-ground timbers have found that the corrosion rates of fasteners in H4 alkaline copper quaternary-treated timber can be approximately four times higher for mild steel and seven times higher for galvanized steel compared to those embedded in H4 CCA-treated timber.

The presence of moisture is important for corrosion of fastenings. A timber moisture content of around 18% is generally accepted as the threshold below which metal corrosion would be very limited in timber. When the timber moisture content is higher than 20% due to exposure to rain, moist air or wet soil, the risk of metal corrosion is significantly increased.

Stainless steel fastenings perform considerably better than mild steel and galvanized steel fastenings (Figure 2). This enhanced performance is recognised in NZS 3604:2011 *Timber-framed buildings*, which requires stainless steel to be used where

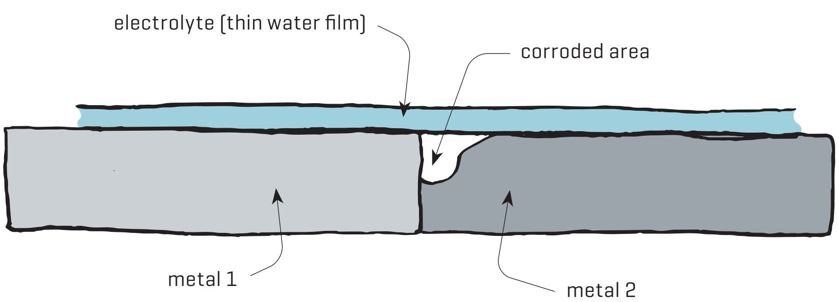

Figure 1. When galvanic corrosion occurs, the less noble metal corrodes at the contact point.

Figure 2. Corrosion of galvanized steel and stainless steel fasteners in timber treated with alkaline copper quaternary after 9 years' above-ground exposure.

fastenings are in contact with timber treated with copper azole or alkaline copper quaternary preservatives in exposed or sheltered locations.

The Building Code and standards and metal compatibility

New Zealand Building Code clause B2 Durability requires that materials will remain functional for certain minimum periods:

- 50 years for building elements that provide structural stability or are difficult to access or replace or where failure may go undetected.
- 15 years for building elements that are moderately difficult to access or replace or where failure would go undetected during normal use but would be easily detected during normal maintenance.
- 5 years for building elements that are easy to access and replace and where failure would be easily detected during normal use.

The relevance of metal compatibility to this is obvious. Galvanized steel fastenings in copper azole and/or alkaline copper quaternary-treated timber that gets wet (such as outside or in contact with the ground or concrete) may not meet the 50-year durability requirement for structural connections. NZS 3604:2011 requires grade 304 or grade 316 stainless steel or silicon bronze fasteners in these situations.

Apart from specifying and using fastenings that meet the durability requirements of the Building Code and standards, there are other ways of reducing the risk of corrosion and premature failure from incompatible metals:

- Designing a building so that water sits on building or building element surfaces for less time. For example, large, flat areas of horizontal surfaces should be avoided, particularly in geothermal areas. Crevices or lap joints that can retain moisture/water (and corrosive chemicals dissolved in the water) for extended periods should be designed out where possible.
- Isolating dissimilar metals with non-conductive, durable plastic or rubber gaskets and nylon or Teflon washers and bushes and polymeric coatings at the joint area. These are widely used for isolation between fasteners and roofing steel sheets.
- Using durable coatings such as paint systems to keep water away from the joints. Check the paint condition regularly. Damaged paint cover may not provide the protection required and may even retain moisture for longer periods, leading to higher corrosion risk.

Conclusion

Metals such as steel, aluminium, copper and zinc are widely used in New Zealand construction, but they have varying levels of compatibility. Direct contact between certain metals in the presence of moisture, particularly with dissolved pollutants such as chlorides in sea salt, can lead to deterioration.

Specifying building components with the appropriate metals and keeping them separated where necessary will lead to longer performance life.

Further reading

BRANZ Facts: Metal corrosion in New Zealand buildings #1 *Corrosion in coastal buildings*

BRANZ Facts: Metal corrosion in New Zealand buildings #3 *Corrosion over the building envelope*

BRANZ Facts: Metal corrosion in New Zealand buildings #4 *Corrosion of metal in timber and concrete*

BRANZ Research Now: Positional corrosion #1 *The impacts of natural elements on different parts of the building envelope*

BRANZ Research Now: Positional corrosion #2 *How different micro-environments around a building envelope affect material corrosion*

BRANZ Bulletin 649 *Corrosion of metals in New Zealand buildings*

BRANZ Bulletin 631 *How micro-environments affect material performance*

BRANZ Study Report SR241 *Corrosion of fasteners in treated timber* (2011)

BRANZ Study Report SR393 *Materials within geothermal environments* (2018)