How metals are protected against corrosion

Metals are often exposed to corrosion over the life of a building. The risk needs to be reduced and managed so that buildings meet their durability requirements under the New Zealand Building Code. Understanding the types of protection available is key to specifying the appropriate materials.

METALS CAN GAIN improved protection against corrosion through a number of means, including:

- developing their own protective surface layers under favourable conditions
- being alloyed with appropriate elements
- being given a protective coating or being painted
- being separated from other corrosive components or elements during the life of the building.

Naturally protective layers

Some metals develop their own atmospheric corrosion resistance as protective layers of corrosion products form on their surface over time. Copper is a well known example, with the metal changing colour as the surface changes take place. Exposed to the atmosphere, the salmon-pink colour of clean copper rapidly disappears due to the formation of a thin surface oxide. On further exposure, the metal darkens to brown and then to black as the oxide grows in thickness. Subsequently, a green layer forms through reactions with atmospheric impurities and provides the typical patinated appearance. Constituents in patina are very complicated and change with time.

Weathering steel also develops a protective layer. This steel has chromium, copper and/or nickel added as key alloying elements. In favourable environments, a dense and well adhering corrosion product layer or patina with self-healing abilities forms on the surface of the steel. This gives weathering steel better corrosion resistance than mild steel. It is not commonly used in house construction but can be found in bridges, loadbearing structures, utility towers and so on. Weathering steel facades feature on the multi-award-winning Ironbank building in Auckland (Figure 1).

Protective layers do not form only as a result of atmospheric exposure but can form from proximity to other materials. The reinforcing steel in concrete is an example. Fresh concrete has a pH of 12.5–13, and this strong alkalinity helps a passive layer some nanometers thick to develop around the reinforcing steel.

Figure 1. The Ironbank building in central Auckland features weathering steel facades.

Some metals can be treated to enhance their naturally protective oxide layer. Aluminium is a good example. Anodisation is an electrochemical process where the native oxide layer on the aluminium surface is made thicker and more durable. The thicker (and/or less porous) the anodising layer, the more the aluminium will resist corrosion from adverse environments. The process has been widely used on aluminium window frames and doors for many years.

Long-term atmospheric testing in New Zealand indicates that anodising provides a very good protection to the underlying aluminium in rural, industrial and marine environments. In some areas, well sealed anodic coatings with a thickness greater than 20 μm could provide a service life longer than 100 years.

Alloying for enhanced corrosion resistance

Alloying is used to make metals stronger and/or more resistant to corrosion – for example, weathering steel with its alloying elements such as copper, chromium and nickel. Stainless steel is another good example, with the steel alloyed with chromium (> 11% by weight). When exposed to a favourable environment, a chromium-rich passive film can form spontaneously on the stainless steel surface to give protection.

The two grades of stainless steel New Zealand designers and builders will be most familiar with are grade 304 and grade 316.

- Grade 304 contains 18–20% chromium and 8–10.5% nickel.
- Grade 316 offers improved protection over grade 304 with the addition of molybdenum (2–3% by weight) and a slightly higher nickel content (10–14%). This makes the steel more resistant to pitting and crevice corrosion in the presence of chlorides (such as in sea salt), which means that grade 316 stainless steel gives a better atmospheric corrosion resistance in marine environments than grade 304.

Zinc coating on steel

Zinc has excellent resistance to corrosion in most atmospheric environments. It is commonly used as a coating on carbon/mild steel to form galvanized steel. Steel treated this way is more resistant to corrosion. Zinc coatings can be produced by electroplating, mechanical plating and hot-dip galvanizing. In general, hot-dip galvanized coating performs better than the other two methods, even if they have the same coating thickness.

Hot-dip galvanized zinc coating is the most commonly used metallic coating system for the protection of carbon/mild steels in New Zealand buildings. The coating is produced by immersing steel into a molten zinc bath and is made up of a series of zinc-iron alloy sublayers metallurgically bonded to the steel substrate. It provides an enhanced corrosion resistance mainly through two main mechanisms:

- A physical barrier that simply prevents contact between the steel and environmental moisture, oxygen and/or pollution.
- Galvanic protection because zinc is more chemically active than steel in almost all environments. When exposed to adverse environments, zinc becomes the anode of a corrosion cell and protects the steel from corroding by making the steel the cathode.

With fabricated building components, the ideal protection comes from hot-dipping the whole component. This provides far better protection than, for example, site treatment of welds.

Although acting as a protective layer, zinc coating cannot completely isolate the underlying substrate from the aggressive environment due to the presence of physical defects. Zinc will corrode slowly and steadily. Eventually, the zinc coating will be consumed to expose the underlying steel substrate to the atmosphere.

Corrosion of zinc coating in an open atmosphere is an approximate straight-line relationship between mass loss and exposure time. Thus, its service life in a specific environment can be estimated directly using its weight or thickness and corrosion rate in the environment. The total coating weight or thickness is a very important parameter for durability. For example, NZS 3604:2011 *Timber-framed buildings* specifies the minimum zinc coating weight for steel components such as bolts, brackets, nail plates, nails and screws to meet Building Code durability requirements.

In New Zealand, the first-year corrosion rate of hot-dip galvanized zinc coating on steel varies from 0.1 to 20 μm/year. High corrosion rates are normally found in severe marine and/or geothermal environments.

Aluminium-zinc alloy coating

Aluminium and zinc alloy coatings have been produced and used since the early 1970s in New Zealand. These coatings have a typical composition of 55% aluminium, 43.5% zinc and 1.5% silicon by weight. AZ150 is the most widely used coating class. It has 150 grams minimum of aluminium/zinc alloy per square metre (the total on both sides) and a nominal coating thickness of ~20 μm on each side. This is very commonly seen on profiled steel roof and wall cladding.

Aluminium-zinc alloy coatings combine some of the best features of both hot-dip galvanized zinc and aluminium coatings, due mainly to their unique compositional and micro-structural characteristics. They have aluminium-rich dendrite and zinc-rich interdendritic regions (Figure 2). An iron/aluminium/zinc intermetallic layer of ~1–2 μm thick is normally formed at the interface between the coating and the substrate.

When exposed to the atmosphere, corrosion takes place in the zinc-rich region preferentially. The corrosion products mechanically lock into the interdendritic spaces, creating a barrier again further corrosion. Consequently, the corrosion rate decreases with time. This type of corrosion can also provide sacrificial protection to cut edges.

Aluminium-zinc alloy coatings typically have a much higher corrosion resistance over hot-dip galvanized zinc coatings in rural, industrial and marine environments – by some estimates, at least 2–4 times.

Other types of hot-dip zinc-based coatings – for example, those alloyed with magnesium – are also available for protection of steels in various environments. Their specifications can be found in AS 1397-2011 *Continuous hot-dip metallic coated steel sheet and strip – Coatings of zinc and zinc alloyed with aluminium and magnesium*.

Protective coatings

Corrosion requires the presence of moisture and oxygen in the atmosphere and can be accelerated with the presence of chlorides from sea salt. Sealing a metal surface against the atmosphere can therefore provide protection, as long as the coating remains in good condition (Figure 3).

Paint is a very common surface coating that can provide an effective barrier. A typical protective paint system usually consists of primer, undercoat(s) and finish coats.

For the best corrosion protection on steel, the paint system should include a zinc-rich primer. These work in a broadly similar way to the zinc applied in galvanizing, as the zinc in the primer coating corrodes in preference to the underlying steel.

Paint coatings can be applied onto steel surfaces by using brush, roller, air spray and

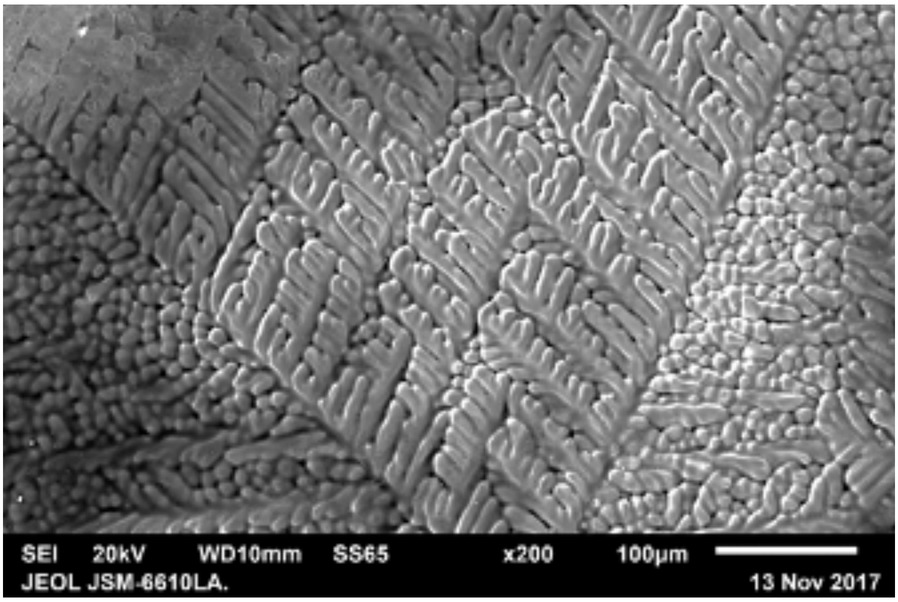

Figure 2. Micro-structure of an aluminium-zinc alloy coating surface.

airless spray. These processes can be done on site or in a factory. A good example of the latter is a profiled steel cladding system with a corrosion-resistant primer and a baked-on multi-coating paint system. The method and conditions of application of a paint system have significant effects on its quality and durability.

Powder coating is different from liquid paint that is delivered via an evaporating solvent. Powder coating is typically applied using an electrostatic spray gun and then cured under heat to form an even film. The powder can be a thermoplastic or a thermoset polymer, typically including polyester, polyurethane, polyester-epoxy, fusion bonded epoxy and acrylics. It is usually used to create a hard finish that is tougher and/or thicker than conventional paint. A typical example is applying polyester powder onto aluminium windows and doors. It is usually a factory process.

While paint of various types is the most obvious protective coating, there are also specialised anti-corrosion coatings available for specific purposes, such as inorganic zinc silicate coatings for steel in coastal environments.

Paint coatings commonly used to protect steel structures in New Zealand environments can be found in AS/NZS 2312.1:2014 *Guide to the protection of structural steel against atmospheric corrosion by the use of protective coatings – Part 1: Paint coatings*.

Separation

Separating certain materials is a proven method of protecting metals against corrosion, particularly galvanic corrosion. This corrosion can take place when noble (cathodic) and less noble (anodic) metals are in direct contact in the presence of moisture and electrolytes such as marine salts dissolved in water. The least noble metal corrodes at the contact point.

Isolating dissimilar metals can be carried out 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 steel roofing sheets.

Separation can also be used in other situations, such as a timber slat deck where steel supporting beams support timber treated with copper-based treatment chemicals. Because the timber is likely to be damp, it may be corrosive to the steel because of the copper retained in the timber from the treatment. An isolating layer such as DPC could be used to prevent direct contact between the steel and the timber, and bolts could be sleeved when they pass through the timber.

Another corrosion risk is experienced with two dissimilar materials that are not in direct contact with each other but subjected to water run-off. For example, water flowing from a prepainted steel surface can induce premature failure of galvanised steel installed underneath it (Figure 4). To avoid this problem, water flow should be guided into structures such as gutters fabricated with appropriate materials.

Corrosion risks associated with incompatible materials can be found within E2/AS1Table 21 *Compatibility of materials in contact* and Table 22 *Compatibility of materials subject to run-off*. The information can provide a guide on whether a separation measure is necessary in a specific environment.

Figure 3. Coatings such as paint must be kept in good condition to remain effective. The mould growth here indicates insufficient maintenance.

Building Code and standards requirements

There are specific requirements for certain types of protection for metallic building elements in the New Zealand Building Code and its Acceptable Solutions and in building standards. Metals and corrosion protection measures must be specified based on the geographical location of the building and where the element is installed on the building. For example, NZS 3604:2011 includes maps with different exposure (atmospheric corrosivity) zones. Buildings in zone D, the coastal zone, are more likely to require galvanized or even stainless steel fixings where exposed to rain and salt winds (Figure 5).

The appropriate level of corrosion protection for different environments is given in documents such as NZS 3604:2011.

Figure 4. Corrosion of galvanized steel induced by water run-off from a painted galvanized steel surface.

The importance of maintenance

While great care can be taken around specifying the appropriate type of metals with the correct level of protection against corrosion, regular maintenance is essential for building element durability and appearance. More aggressive environments – close to breaking surf beaches, geothermal features or factories with corrosive emissions – require more frequent maintenance than benign environments such as rural locations.

Figure 5. The appropriate level of corrosion protection for different environments is given in documents such as NZS 3604:2011.

The key step is regularly checking the state of building elements. Beyond this, basic maintenance tasks include:

- washing down surfaces, particularly exterior building elements subject to wind-driven salt spray or geothermal or chemical influences
- recoating protective finishes as required
- replacing sealant and seals.

Ensuring that protective coatings remain intact is an important part of maintenance. Rust can form underneath deteriorating paint films, and if the damaged paint is holding moisture and airborne contaminants on the metal surface, it can actually speed up corrosion rather than protect against it. Because rust has a much greater volume than steel, it expands beneath the paint film, causing blistering, cracking and/or flaking, allowing corrosion to accelerate or spread over larger surface areas.

Building owners should be given the maintenance recommendations by product manufacturers or suppliers. For example, a large New Zealand manufacturer of sheet steel claddings says that, for its wall claddings, unwashed and high-risk areas require manual washing every 3 months in the most severe environments and 6 months or annually in other environments.

Conclusion

Uncontrolled corrosion of metals can result in elements on buildings not meeting the required performance and durability. Understanding how metals are protected and specifying building materials with the correct types of protection is crucial for achieving the durability requirements of the Building Code. In many cases, specific requirements are set out in building standards and/or Acceptable Solutions.

Metals can gain improved corrosion resistance through a number of means, including:

- developing their own protective surface layers – copper and weathering steel are good examples
- being alloyed with other elements – stainless steel with chromium added is a good example
- being given a protective coating – zinc is commonly used on carbon/mild steel, while paint and specialised coatings can be used on a range of metals such as aluminium and zinc
- being installed so that they remain separated from other elements during the life of the building.

Building owners must also be given maintenance requirements.

Further reading

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

BRANZ Facts: Metal corrosion in New Zealand buildings #2 *How metals interact in the built environment*

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 Facts: Metal corrosion in New Zealand buildings #5 *Atmospheric corrosivity classification*

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 Bulletin 574 *Preventing corrosion of reinforcing steel in concrete*