The performance of aluminium-zinc alloy coating in geothermal environments

BRANZ examined the corrosion of aluminium-zinc alloy-coated steel in geothermal environments in a 2-year field trial. At the same time, identical samples were exposed to a marine environment. The results show that these coatings degrade and fail more quickly in a geothermal environment than a marine environment. Explanations for this are suggested.

BRANZ conducted field trials in Rotorua to examine how different metals corrode in geothermal environments. The metals included mild steel, stainless steel, aluminium, copper, zinc and aluminium-zinc alloy-coated steel. This Research Now covers the findings for the alloy-coated steel.

The 55% Al-Zn alloy coating used in the research is typically made up of 55% aluminium, 43.5% zinc and 1.5% silicon by weight. This formulation was first developed in the United States by the Bethlehem Steel Company. Production at the BHP New Zealand Steel Glenbrook plant started in 1994. Al-Zn alloy-coated steel is widely used in New Zealand today, particularly as roof and wall claddings, spouting and downpipes.

The field trial

The testing samples had a typical dimension of 150 × 100 × 1-3 mm. They were fixed in racks and exposed in three locations:

- Approximately 5 m from an active small fumarole (a natural vent that emits sulphurous gases) in the grounds of Scion, a Crown research institute in Rotorua.
- At the wastewater treatment plant site approximately 200 m south of Sulphur Bay, near the southeastern corner of Lake Rotorua. This area has many active geothermal features.
- In a severe marine environment at Oteranga Bay on Wellington's south coast, to allow comparison with a different type of aggressive environment.

Galvanic corrosion risks in atmospheres with geothermal emissions were also investigated. Galvanic pairs were prepared using samples of aluminium, copper, stainless steel, zinc and steel with 55% Al-Zn alloy coating.

Structure of Al-Zn alloy coating

The 55% Al-Zn alloy coating has a complex microstructure with an aluminium-rich phase and a zinc-rich phase (Figure 1). The aluminium-rich phase forms into dendrites - tiny metallic crystal structures that look a bit like snowflakes or trees. The zinc-rich phase occupies the regions between the dendrites and is therefore often called the interdendritic phase. The dendrite constitutes approximately

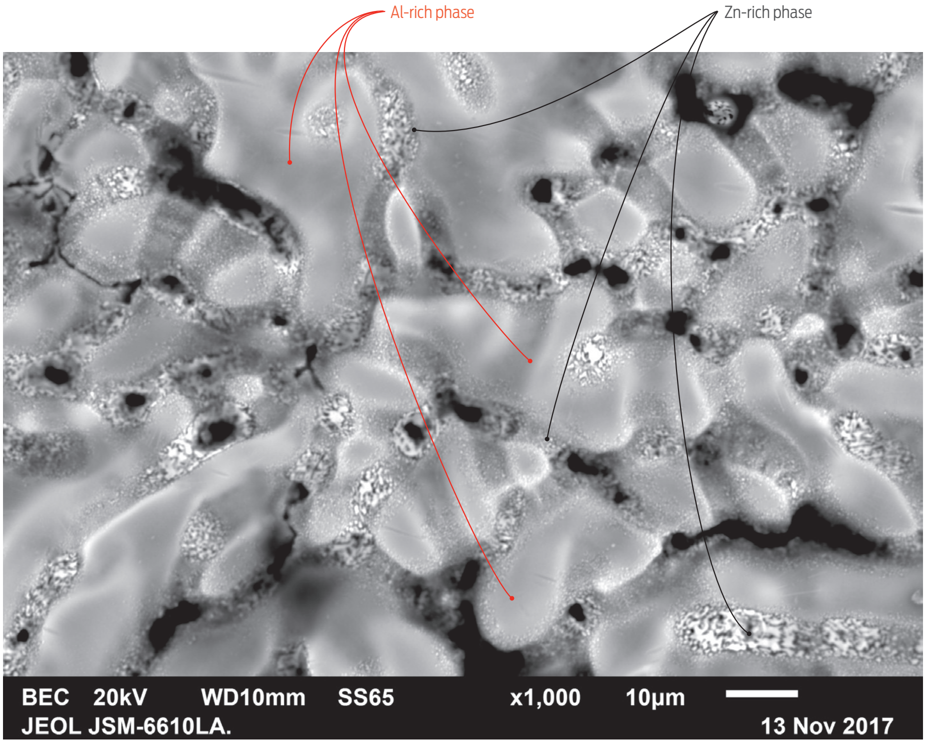

Figure 1. Typical surface structure of a 55% Al-Zn alloy coating.

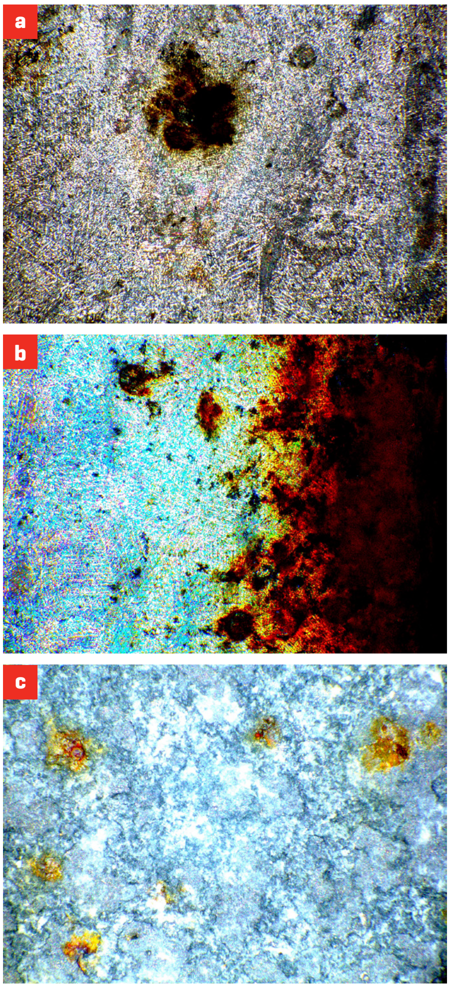

Figure 2. Surfaces of Al-Zn alloy coatings after a 2-year exposure at a) approximately 5 m away from a fumarole (Scion campus), b) the wastewater treatment plant approximately 200 m south of Sulphur Bay and c) Oteranga Bay (severe marine).

80% of the coating volume. An intermetallic layer made up of two sublayers (a quaternary Fe-Al-Si-Zn and a ternary Fe-Al-Si) is normally formed to metallurgically bond the coating to the steel substrate. Silicon can also be present in the microstructure as needle-like particles in the interdendritic regions.

How the Al-Zn coated steel performed

After a 2-year exposure in a geothermal environment, the alloy-coated surfaces of the samples did not show heavy rusting. The coating deterioration that was seen was mainly a number of small, randomly distributed rust spots on the surface (Figure 2a). This indicates that the alloy coating has been consumed locally, and some parts of the steel substrate have then been exposed to the aggressive environment directly.

Heavy rusting was seen close to the unprotected cut edges (Figure 2b). This indicates that the exposed steel cannot be effectively protected by the cathodic protection effect normally lent by zinc coating in many natural environments.

Spot rusting was occasionally seen on the samples exposed to the severe marine environment together with the formation of some grey/white patches (Figure 2c). Rusting was limited to small areas close to the bottom cut edge. Relatively severe damage to the coating was seen in some areas on the top surface, but this was the result of mechanical impact from wind-blown sand or salt particles.

The aluminium-zinc alloy coating combines features of both hot-dip galvanised (zinc) and aluminium-based coatings. When exposed to the atmosphere, corrosion takes place first in the zinc-rich region at the outer surface of the coating. The corrosion products create a barrier against further attack. As a result, corrosion normally slows down over time. This type of corrosion can provide sacrificial protection to cut edges in many atmospheric environments.

Aluminium in the coating can provide protection only when it is activated, such as in marine or industrial environments. Overall, aluminium-zinc alloy coatings show better corrosion resistance than hot-dip galvanised zinc coatings in many natural environments.

Corrosion of steel with a 55% aluminium-zinc alloy coating appears to follow the general pattern when exposed to geothermal environments, though with some differences.

Energy-dispersive X-ray spectroscopy found enrichment of sulphur and oxygen in the zinc-rich surface areas and attacks to them after exposure to a strong geothermal environment. As revealed by BRANZ tests, loose corrosion products rich with zinc sulphide are normally formed on zinc exposed to environments with high levels of airborne sulphur-containing gases. These corrosion products do not provide a good protection to the underlying substrate. Consequently, zinc-rich areas of the Al-Zn alloy coating are attacked preferentially and consumed quickly, producing physical and

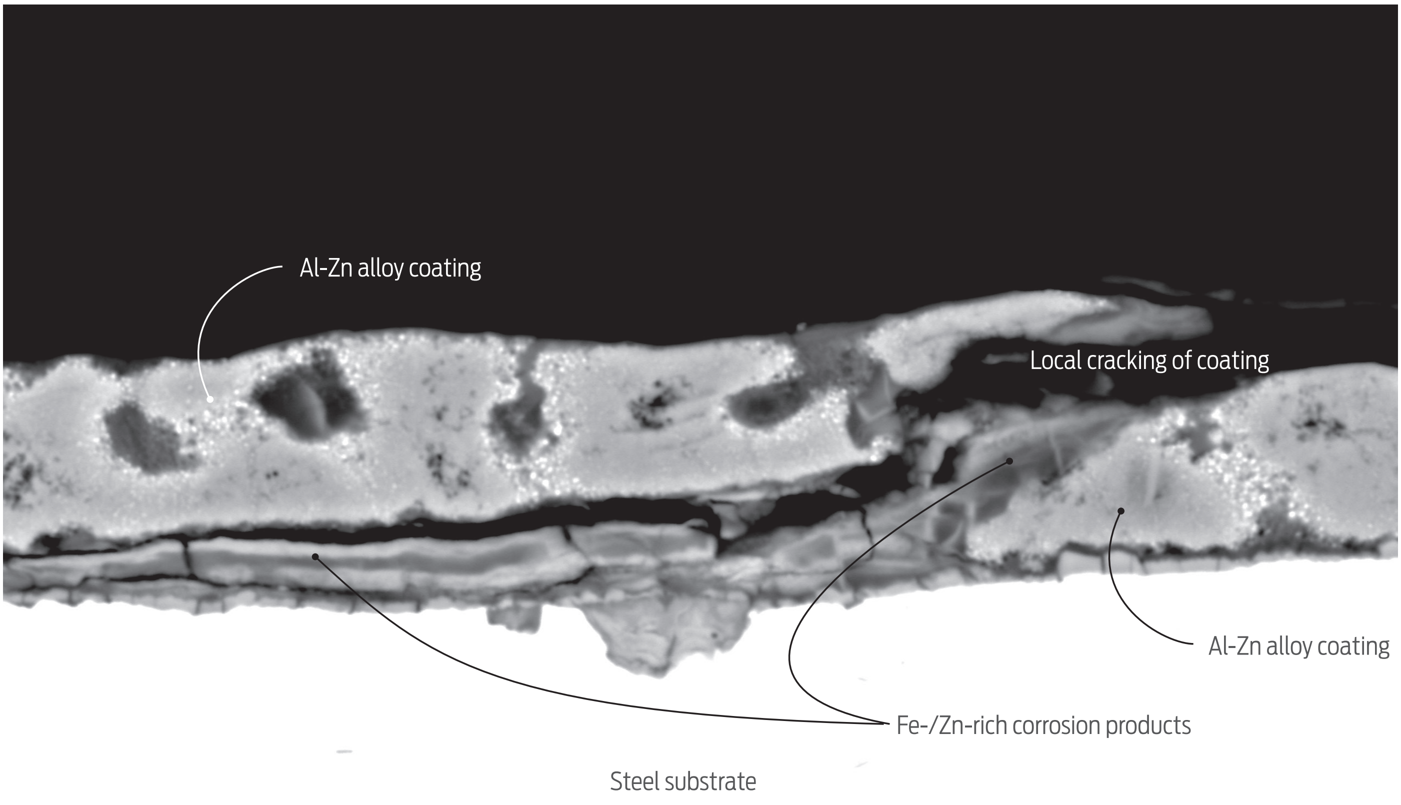

Figure 3. Cross-sectional view of a 55% Al-Zn alloy coating after a 2-year exposure to a strong geothermal environment.

structural defects in the underlying coating.

Sulphur-containing gases may then easily enter the inner part of the coating or the substrate through these defects, which act as fast channels and attack Al-Zn coated steel. This process may happen more quickly when compared with that in marine environments where solid salt particles are the major corrosive agent. As a result, iron-rich corrosion products (sulphides and/or oxides) could form quickly at the coating-steel substrate interface (Figure 3). This leads to a large volume expansion in confined spaces. The huge stresses generated could produce more physical defects in the coating such as bubbles or cracks (Figure 4). During extended exposure, severe localised attack to the steel substrate will be promoted along the interface. This leads to larger volume expansion, more damaged areas and finally coating failure, normally shown as the formation of iron-rich rust on large surface areas.

Galvanic corrosion

When two dissimilar conducting materials are in electrical contact and exposed to a corrosive environment, galvanic corrosion can happen. The anodic or active material will be corroded first. This corrosion may happen more severely or may be different to the normal corrosion when there is no electrical connection between the two materials. Galvanic corrosion causes performance issues on buildings when different construction materials are in direct contact or there is water run-off from one material onto another.

This study tested galvanic corrosion risks of metallic pairs when exposed to strong geothermal environments. Metallic samples approximately 40 × 40 mm were prepared with aluminium, copper, stainless steel, zinc and 55% Al-Zn alloy-coated steel.

Mass losses and surface damage were seen with stainless steel that was assembled with 55% Al-Zn alloy coating after a 1-year exposure starting from December 2014. Pits were developing under the white corrosion products. Although some changes were noticeable, there was no severe degradation of the Al-Zn alloy coating.

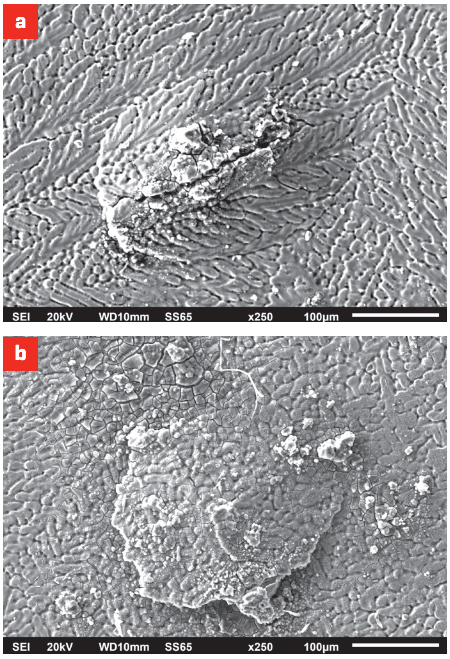

Figure 4. Failures seen on 55% Al-Zn alloy coatings exposed to a strong geothermal environment: a) bubbling/cracking, b) lifting up.

This finding was unexpected. According to Acceptable Solution E2/AS1 Table 21 *Compatibility of materials in contact*, direct contact between stainless steel and Al-Zn alloy coating should only be avoided in the sea spray zone or Zone D (NZS 3604:2011 *Timber-framed buildings*) where there is a high chance of salt deposition. Al-Zn alloy coating would be the material expected to see accelerated attack with this contact.

In this study, the degradation was found at the areas where materials were directly in contact. This indicates that crevice corrosion may be the cause. Electrolytes, such as rainwater, could not stay on the 45° tilted sample surface for extended periods during atmospheric exposure. However, the areas of contact would be able to collect and retain moisture and/or air contaminants for long periods. This would provide an ideal situation to promote localised corrosion on the stainless steel surface.

The mechanisms behind this may be better understood with appropriate long-term experimental testing.

Conclusion

The field trial indicated that, with Al-Zn coatings, the corrosion process in strong geothermal environments may happen more quickly when compared with other aggressive atmospheric environments such as marine environments. 55% Al-Zn alloy coatings have reasonably long service lives of around 10–15 years in severe marine environments before significant surface rusting occurs (shown by tests in the United States). This is much longer than currently observed in strong geothermal environments.

More information

BRANZ Study Report SR393 *Materials within geothermal environments*

BRANZ Research Now: Geothermal corrosion #1 *Which metals are more sensitive to geothermal corrosion?*

BRANZ Research Now: Geothermal corrosion #2 *Distance effects of corrosion in geothermal environments*

BRANZ Research Now: Geothermal corrosion #3 *Discolouration and deterioriation of wood in geothermal environments*