The science behind durability

Because there are so many variables, understanding the durability characteristics of different building materials involves complex science. For many years, BRANZ research has helped improve our knowledge, inform the New Zealand Building Code and ensure our buildings are more durable.

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THE PERFORMANCE-BASED New Zealand Building Code (NZBC) requires any building materials and components to be sufficiently durable, as defined by the standards given. This ensures the building continues to satisfy the functional requirements of the Building Code throughout its specified life. Consequently, durability needs to be considered thoroughly in design, specification, construction and usage.

Durability specification challenging

The durability of a building component depends on the fundamental properties of the material used, the environment it encounters and complicated interactions with other components.

This provides an interesting conundrum since different building components have different durability requirements. For example, they can range anywhere from an external gutter that lasts for 5 years to a steel structural frame that must withstand a minimum 50 years of use according to the NZBC.

Therefore, durability interpretation and specification are challenging. A good understanding of how and why a material behaves the way it does can help identify a cost-effective component that enables it to endure the stress of a specific application - that is, it allows it to meet the NZBC durability requirements.

Micro-structure matters

Zinc-based coatings are commonly applied onto fasteners using hot-dip galvanising and mechanical plating. As might be expected, these should demonstrate similar durability if they have a similar composition and thickness.

However, field testing shows that mechanically plated screws fail faster than hot-dip galvanised nails when embedded into preservative treated timbers (see Figure 1). Why does this happen?

Although these two coatings are similar in composition and thickness, they do have essential micro-structural differences. The coating produced by hot-dip galvanising in a molten zinc bath is dense, uniform and metallurgically bonded to its steel substrate. In comparison, the mechanically plated coating is porous, non-uniform and weakly bonded since zinc powders are cold-welded onto the steel surface to form it.

When driven into preservative-treated timbers, the mechanically plated coating will be partially damaged.

Furthermore, moisture and copper ions from the timber treatment can easily enter the pores in the coating. This will significantly accelerate corrosion attack and destroy the coating integrity more quickly, resulting in a shorter durability.

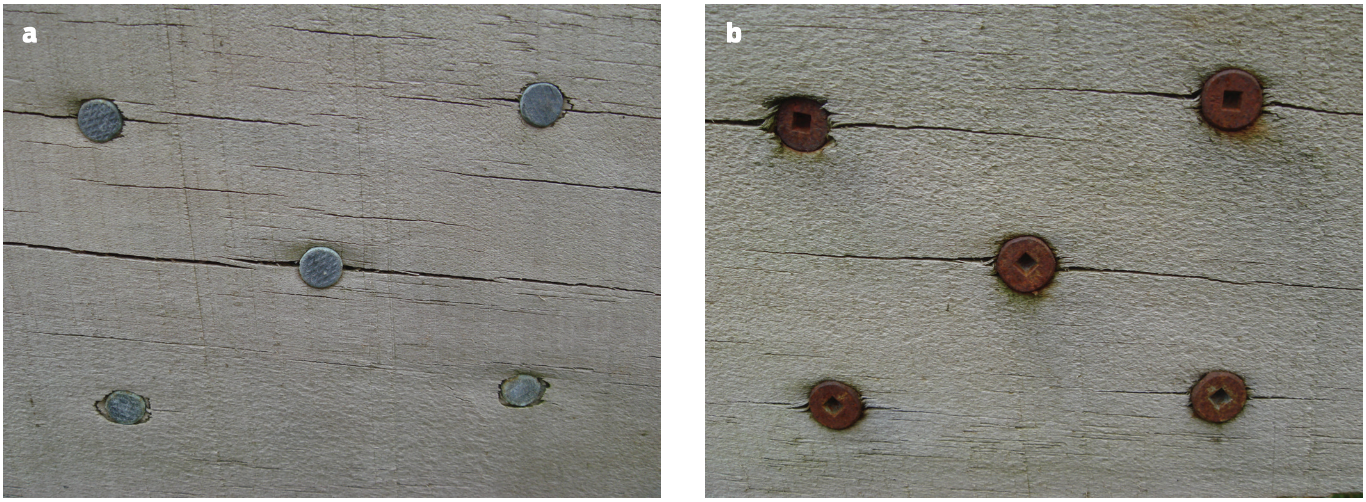

Figure 1: Durability of (a) hot-dip galvanised nail and (b) mechanically plated screws embedded into H4 copper azole and exposed at the BRANZ site in Judgeford for 3 years. Their zinc coating thicknesses are similar – approximately 50 µm.

Composition effects

An addition of aluminium into hot-dip galvanised zinc creates various aluminium-zinc alloy coatings - for example, 5 wt.% Al-Zn and 55 wt.% Al-Zn. This alloying addition leads to significant changes in the composition and micro-structure of these coatings. As an example, the 55 wt.% Al-Zn alloy coating has aluminium-rich dendritic and zinc-rich interdendritic regions (see Figure 2).

When the 55 wt.% Al-Zn alloy coating is exposed to the atmosphere, corrosion takes place first on the zinc-rich region. The corrosion products mechanically lock into the interdendritic spaces, producing a physical barrier against further attack. In marine or industrial environments, aluminium-rich dendrites will be activated so that the coating will combine the beneficial features of both zinc and aluminium coatings. Consequently, it performs much better than a conventional hot-dip galvanised zinc coating.

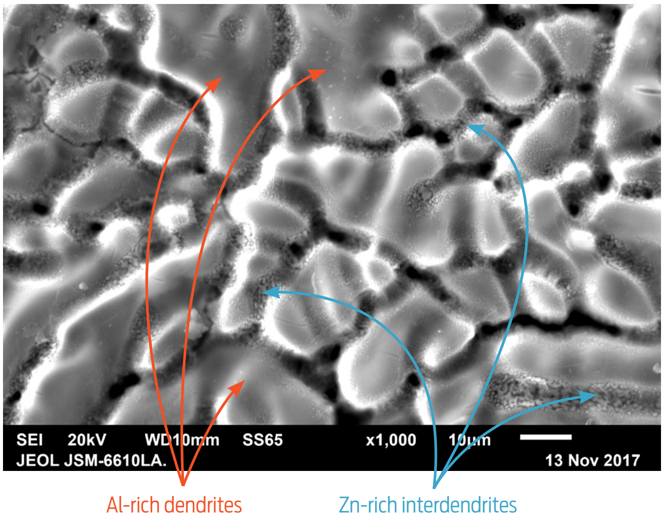

Figure 2: Typical surface morphology of a 55 wt.% Al-Zn alloy coating.

Understanding durability from the very bottom

These compositional and micro-structural influences, unveiled by powerful materials characterisation techniques such as electron microscopy, spectrometry and X-ray diffraction, provide valuable insights:

- The basic characteristics of a material, such as composition, micro-structure and processing, interact in a complex manner to affect its properties (see Figure 3).
- The durability of a building component is fundamentally interrelated to the properties of the material from which it is made.

This knowledge constitutes a set of building blocks, in a sense, that allow us to establish a baseline to understand and evaluate durability through a bottom-up approach.

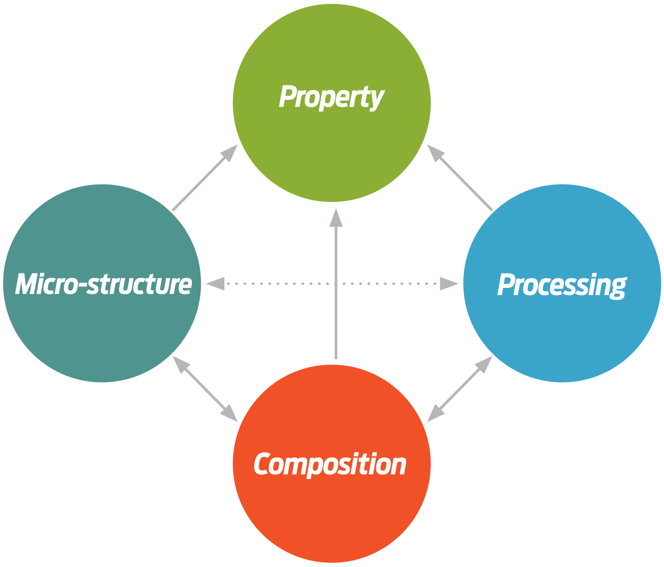

Figure 3: Correlations between composition, micro-structure and processing of a material.

Durability specifically related to environment

As noted, the 55 wt.% Al-Zn alloy coating has an enhanced durability in marine or industrial environments. However, this might not be the case in geothermal environments.

When exposed to strong geothermal environments, its zinc-rich interdendritic regions will be attacked preferentially by sulphur-containing gaseous species. Corrosion products rich with zinc sulphide have various physical and structural defects through which sulphur-containing gases can easily enter the inner part of the coating and attack the steel substrate directly.

Iron-rich corrosion products - for example, oxides and sulphides - can form quickly at the coating-steel interface with a large volume expansion and cause stresses (see Figure 4). The coating integrity will be destroyed and eventually the coating will fail.

This illustrates perfectly why durability should be closely reviewed and the in-service environment considered when selecting materials.

Durability test – doing it right

Various methods and procedures have been developed for durability evaluation. One typical example is continuous salt spray for metals, coatings and paints. However, a poor correlation is always observed between the test results and in-service performance. Why?

This test features non-stop wetting with a sodium chloride solution (5 wt.%) and a constant high temperature of 35°C. These configurations don't reflect most in-service environments, leading to different material degradation pathways. For example, zinc or zinc-based coatings are unlikely to develop a protective corrosion product layer on the surface as they do when exposed to real atmospheres.

Understanding this paved the way for the development of so-called prohesion and other advanced cyclic methods. These incorporate regular temperature variations, alternated wet-dry cycles, UV irradiation and condensation cycles for better environment simulation to deliver better results.

Therefore, systematic knowledge of the effects of critical environmental factors on material degradation will help durability evaluation go beyond the test and see type characterisation. It will then be carried out in an integrated, whole systems context with a significantly enhanced quality of outputs.

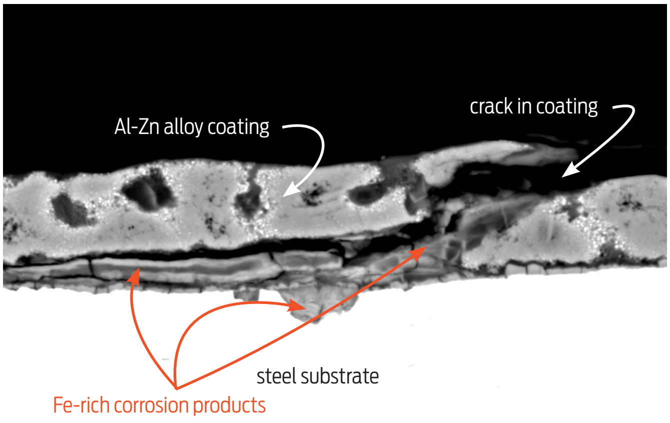

Figure 4: Cross-sectional view of the degradation of a 55 wt.% Al-Zn alloy coating after a 2-year exposure to a strong geothermal environment (Fe = iron, Zn = zinc, Al = aluminium).

Supporting the leap ahead

Theoretical and experimental advances have made steady progress in durability evaluation. This leads to the question, what's next? There are opportunities for artificial intelligence (AI), particularly deep machine learning, using big data to pursue grand challenges and discover new frontiers.

However, the accuracy and reliability of AI techniques are yet to be fully exploited, particularly when their limitations are considered:

- The learning algorithms and architectures are determined manually by trial and error.
- There is little understanding of what is going on inside the black box.

To refine AI techniques for better-informed durability evaluation, in-depth knowledge from a material science perspective would help. This might include:

- relationships between composition, microstructure and processing at the material level
- mechanisms behind material degradation and failure models
- attributes of the interactions between materials and their environments.

For more See summaries of relevant BRANZ research in BRANZ Facts *Metal corrosion in New Zealand buildings* and BRANZ Research Now *Positional corrosion* and *Geothermal corrosion*, available from www.branz.co.nz.