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Durability Assessment of New Generation Coated Steel Technologies for use in Building and Construction: Methodology and a Case Study

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ABSTRACT

Coated sheet steel is widely used in roofing, cladding, framing and rain water goods, with proven field performance in a number of environments. In recent years, a range of coating developments has been brought to market to extend the product life or reduce the overall cost of corrosion.

The development of the new generation of metallic coatings provides a challenge in determining whether the benefits seen in accelerated testing are delivered in the field. Determining the expected field life is critical for all stakeholders, in terms of addressing warranty offers, Standards and Building Code certification, life cycle analysis and so on.

BlueScope Steel has been active in the research, development and commercialisation of coating technologies over many years, including both metallic and polymer coatings. This has led to the development of expertise in assessing and understanding accelerated and long-term coated steel performance and durability, and the relationship between these assessments.

This paper discusses the approach taken to the assessment of new generation coatings, and in particular the scale-up from accelerated testing to service life assessment. The critical nature of this work in ensuring that commercial building products meet the durability requirements expected of them is discussed, along with the recent case study around the development of the next generation aluminium-zinc-magnesium (AM) metallic coating for the building market.

KEYWORDS

Durability, Steel, Metallic coatings, Buildings.

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1 INTRODUCTION

The durability of coated steel is infleunced by a number of environmental factors, including:

- the rate of deposition of corrosive media, such as marine salts and industrial pollutants,
- the rate of removal (or washing) of corrosive media, and
- micro and macro climactic influences, such as humidity, condensation and temperature.

Galvanized steel has been widely used since the 1830s [Roberge 2000], providing an understanding of the product's durability and the impact of environmental factors. Over the years, coatings have been developed to prolong the durability of steel. A number of these coatings technologies, such as the Galvalume® steel 55%Al-Zn coating, Galfan® 95%Zn-Al, Aluminised 90%Al-Si and Terne have been around for decades, allowing study of their outdoor performance in a range of environments.

A suite of new technologies, summarised in Table 1 (Shedden [2010]), has recently been brought onto the market. These technologies combine zinc, aluminium and magnesium in the metallic coating, with the bulk of the coating being zinc. A study by Prosek *et al.* [2009] of these types of coatings showed that "… (t)he corrosion stability of Zn-Mg and Zn-Al-Mg coatings strongly depended on the exposure conditions. Although it was superior to zinc reference materials under all experimental conditions, improvements from low tens of per cent up to 10-fold drop in corrosion rate were observed". Given this range, the durability of these new generation coatings requires thorough assessment, to determine suitability for various applications in the construction industry.

Table 1. Summary of some of the recently introduced metallic coated steel technologies.

Composition	*Brand*	*Manufacturer*	*Reference*
Zn-6%Al-3%Mg	ZAM®	Nisshin Steel	De Bruycker [2006]
Zn-11%Al-3%Mg-0.2%Si	SuperDyma®	Nippon Steel	De Bruycker [2006]
Zn-5%Al-0.8%Mg	ECOGAL®	JFE Steel	Fujisawa *et al.* [2009]
Zn-1.5%Al-1.5%Mg	MagiZinc™	Corus Group	Vlot *et al.* [2006]
Zn-1.5%Al-1%Mg	ZMg EcoProtect™	ThyssenKrupp Steel	Lamprecht [2009]
Zn-2%Al-2%Mg	Correnderᵀᴹ	voestalpine	voestalpine [2010]

2 DURABILITY EXPECTATIONS OF COATED STEEL IN BUILDING APPLICATIONS

The current widespread use of coated steel is in part due to the market confidence in the durability of these products. In developing new coated steel technologies, it is important to highlight the durability expectations, to allow an understanding of whether the new techologies are able to deliver against these expectations. Without meeting the expectations, the technologies may not be widely accepted.

2.1 Building Code of Australia

The Australian Guidelines on Durability in Buildings [Australian Building Codes Board 2003] provide an indication on the design aspirations for various components of buildings in Australia (Table 2). Apart from the Guidelines, the Building Code of Australia does not provide direct indications of durability requirements. However, for metallic coated steel, specific coating masses are required to meet the Deemed to Satisfy provisions of the Code. The implication of this is that the coating masses referred to have been proven over the years to provide adequate performance to meet consumer expectations. A comparison to incumbent products is therefore a starting point for the introduction of new coating technologies, with testing aligned to the applications covered in the Code.

Table 2. Extract from the Australian Guidelines on Durability in Buildings.

Design Life of buildings (dl) (years)		*Design Life of components or sub-systems (years)*		
		Category		
Category	*Number of years*	*Readily accessible and economical to repair*	*Moderate ease of access but difficult or costly to replace or repair*	*Not accessible or not economical to replace or repair*
Short	1 < dl < 15	5 or dl (if dl<5)	dl	dl
Normal	50	5	15	50
Long	100 or more	10	25	100

2.2 Durability Warranties

Under Australian Law, there are two forms of warranties – contractual and statutory. The former is an explicit statement outlining the warranty a manufacturer provides for the product, given certain requirements (terms and conditions) are met. The latter is provided by legislation, and provides consumers protection that the product is of merchantable quality and is fit for purpose.

Contractual warranties for coated steel in Australia vary in duration. BlueScope Steel, for example, provides warranties ranging from 10 years to 50 years, under certain conditions. The widespread acceptance and market application for these warranties provides a baseline level of durability expectation.

The duration of the statutory warranties for coated steel in Australia has not been fully tested. They are based on what a reasonable consumer would expect, which in part will be influenced by past performance, technical data and marketing communications. While of importance, they have a maximum duration of 10 years from the date of purchase of the product.

3 DETERMINING FIT WITH DURABILITY EXPECTATIONS

In order to understand whether new generation coated steel technology will provide the required durability, which, depending on the current warranty, code or other expectation, may be in excess of fifty years, a range of product assessments is essential.

3.1 Accelerated Testing Alone

While accelerated testing provides a comparison of corrosion performance, it can be limited in direct application. GalvInfo [2009] stated that "…(f)or an accelerated corrosion test to be truly useful, a prime requirement is that the results correlate with performance in the real world, something that has never been demonstrated with the salt spray test (one of the key accelerated tests). This has led many researchers to conclude that the test has no relevance, and should be discontinued". Shedden [2010] similarly found limited evidence for the correlation between a range of accelerated tests and real world corrosion performance.

In general, accelerated testing relies on the corrosion mechanisms and relative kinetics for the new coatings being similar to the corrosion mechanisms for the coatings being compared to. This is not necessarily the case. The relative kinetics of corrosion in the accelerated test can be quite different to washed outdoor exposure. As an example, in salt spray testing, Zn-6%Al-3%Mg coated steel (ZAM®) has shown 10-20 times the life of galvanised steel, while in outdoor testing after 7 years, the ZAM® coated steel has a projected life in a washed environment of 3-4 times galvanised steel [Nisshin Steel Corp 2008].

3.2 Washed Outdoor Testing of Panels Alone

Washed outdoor testing of panels are more likely to experience corrosive environments, mechanisms and kinetics similar to real world full scale buildings. However, there are shortfalls. The kinetics of washed outdoor corrosion can be quite different to sheltered outdoor exposure. In sheltered exposure, the build-up of corrosive salts continues without any washing to remove these salts. Such a situation occurs in open buildings (e.g. walkways, carports, sheds, hangars), on the top surface of roofs under ridge capping, and inside roof cavities. Kimata *et al.* [2007] showed that in sheltered exposure, three metallic coatings on steel showed significantly greater corrosion than in washed exposure.

Interactions occur in buildings that may not be seen on panels. In an application such as roofing, there are interactions with fasteners, battens and flashing. An example of the flashing issue is evident where lead was used for flashing roofs. The interaction between lead and Galvalume® coated steel caused accelerated corrosion of the Galvalume® steel [NSW Heritage Office 2004]. Similarly, the replacement of galvanised steel with Galvalume® coated steel for roofing increased the purity of the rain water running off roofs and into gutters; the result was an inert catchment affect, where the corrosion of galvanised steel gutters was rapidly accelerated [Tyler 2008].

4 A SCALE-UP APPROACH FOR ASSESSING COATED STEEL PRODUCTS

A scale-up approach allows assessment of various factors that can affect the life of coated steel in buildings in a way that mitigates risk and progressively develops confidence in a coated steel product. Such an approach involves the use of various test methodologies, including

- standard accelerated tests,
- standard panels in outdoor exposure in various environments,
- sophisticated panels in outdoor exposure in various environments,
- various different laboratory-scale application assessments,
- multiple ‘installed sites’, with small volumes of product in real-world assessment, and
- full-scale buildings in various sites.

The approach is shown schematically in Fig. 1. Examples of each stage of the product assessment are shown in Table 3. The progressive increase in confidence assists in determining the ‘real world’ durability, leading to development of performance statements, warranties, building practices, LCA durability inputs, and meeting of Building Codes and Standards.

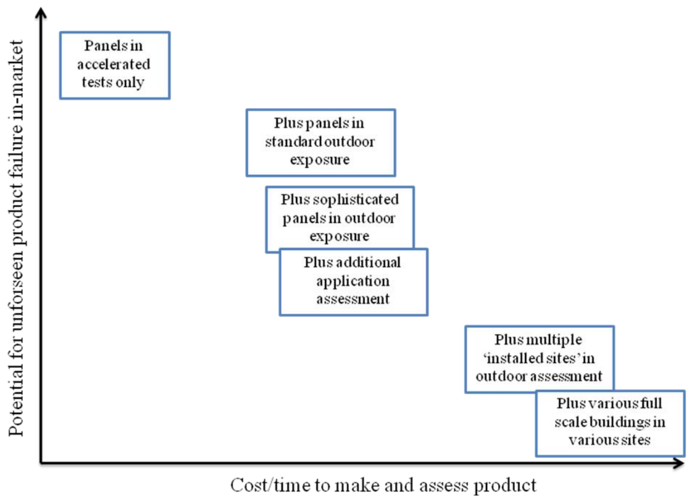
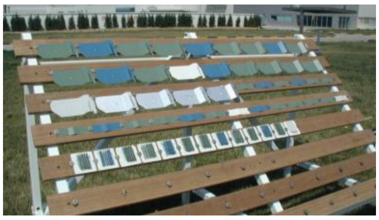
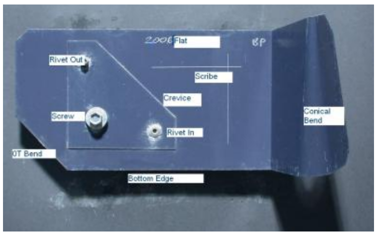
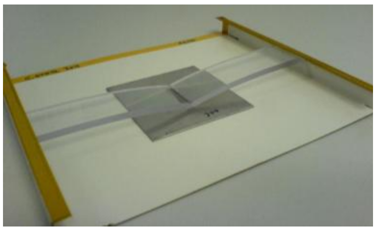


Figure 1. Schematic indicating the progressive reduction in risk as the investment in the scale-up approach for coated steel assessment progresses.

Table 3. Examples of tests performance at each stage of assessment in a scale-up appraoch.

Stage	*Assessment Examples*	
1. Accelerated testing	 a) Panels in QFog cyclic corrosion test.	 b) Panels in the Salt spray test.
2. Standard outdoor	 a) Marine outdoor assessment site (Bellambi Point in Australia).	 b) Acid rain outdoor assessment site (Cheng Du in China).
3. Sophisticated panels, including interaction assessment	 a) Sophisticated panel, incorporating rivets, screw, overlap panel and a 0T bend, allowing interactions and other factors to be assessed.	 b) Dissimilar metals panel, with one metal held in contact with the coated steel and then assessed outdoors.
4. Laboratory / small scale, including interaction assessment	 a) Assessment in a guttering (inert catchment) application, while also assessing the run-off.	 b) Assessment of product immersed in concrete.
5. Installed applications	 a) Assessment Hut comprising various building components.	 b) Shed door on Surf Life Saving Club, located at ocean beach.

4.1 Case Study: The Development of Al-Zn-Mg Coating Technology

Table 1 indicated that recent developments in coated steel have been based on zinc, with additions of aluminium and magnesium. By comparison, BlueScope Steel has focused on using the aluminium-zinc (or AZ) (Standards Australia 2010) coating as a starting point, and identified the factors which could improve the overall durability of coated steel in building applications. The resulting product has been optimised, through the range of testing, to produce the aluminium-zinc-magnesium (or AM) (Standards Australia 2010) coating. The following section details the history of the development of this composition, testing results and discusses the comparative findings at the different stages.

4.1.1 History of the development of the Al-Zn-Mg coating

Work at BlueScope Steel commenced in the early 1990s, with small panels produced with a range of compositions. This included various different levels of magnesium addition to the AZ coating. Over the subsequent two decades, the scale-up approach was applied to optimise the composition, and determine the performance in a range of applications and environment. This is summarised in Fig. 2.

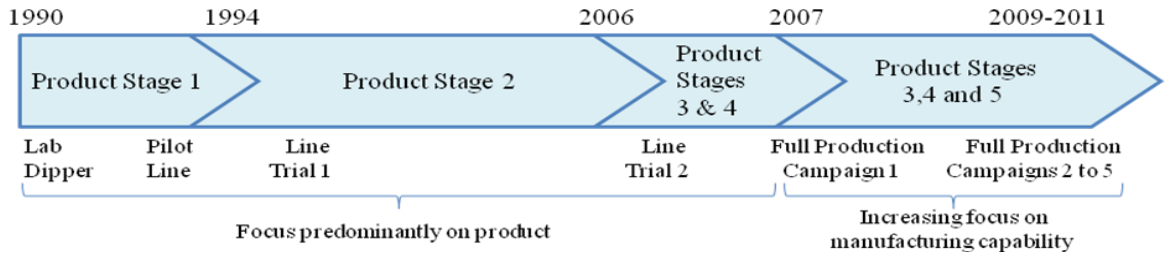


Figure 2. Timeline for the development of Al-Zn-Mg coating technology

4.1.2 Test methods discussed in this paper

The scale-up approach employed a broad range of tests. The tests (Table 4) and results presented in this Case Study focus on the key understandings elucidated from this approach.

Table 4. Selected tests from the development of the AM coating that gave greatest range of learnings and highlighted the benefit of the scale-up approach.

Stage	*Test Method*
1. Accelerated testing	a. Cyclic Corrosion Test (CCT): CCT-1, or Cycle E from AS2331.3.13. b. Neutral Salt Spray: ASTM B117
2. Standard outdoor	a. Outdoor mass loss: Method as per Townsend and Zoccola (1979). b. Outdoor general corrosion assessment of surface, edges and bends: Formed panel with a scribe and 3T and 5T bends, facing north installed at 45° at various test sites in Australia.
3. Sophisticated panels	Outdoor general corrosion assessment of surface, edges, bends, laps, around rivets and screws a. Standard panels with the addition of a lap, rivets and screws. b. Sheltered panels incorporating a conical bend ranging from 10T to 20T, a 0T bend, a lap with rivets and screws. c. New panel with side-by-side bends ranging from 0T to 6T.
4. Lab scale, including interaction assessment	a. Run-off simlulation of catchment and gutter, as shown in the guttering (inert cathcment) example in Table 3. b. Sets of standard panels inserted in various types of concrete, with the concrete broken open for inspection of panels after 1 month, 1 year or 3 years.
5. Installed applications	Assessment Huts comprising roofing, walling, fencing, rain water goods, framing, garage doors and gutter guards in 5 different corrosive environments in Australia. Water run-off captured and analysed for elemental content.

4.1.3 Selected results and discussion around the Scale-Up Approach

<u>Stage 1 and 2 comparison</u>: Unpainted AZ and AM coated steel samples were assessed in the accelerated tests, with the AM product outperforming the AZ product (Table 5). However, for

painted AM product, certain paint systems in salt spray testing exhibited unusual blister formation commencing from the cut edge. By comparison, the accelerated cyclic corrosion testing and the Stage 2 outdoor assessment did not show this behaviour, but rather exhibited standard blistering appearance. Further, the rate of edge corrosion on the AM coating was around ½ of that on the AZ coating in both the accelerated cyclic corrosion test and outdoor assessment. Having the Stage 1 and 2 product available allowed assessment of corrosion mechanisms, indicating that the salt spray assessment, by keeping the corrosion product continuously wet, did not allow the drying and barrier protection mechanism form that occurs in either the 'real world' or the accelerated cyclic corrosion test.

Table 5. Amount of corrosion as measured by surface metallic coating mass loss (g/m^2) for the AZ and AM coated steel samples after 5 weeks in CCT-1 (Cycle E or QFog) cyclic corrosion testing. The samples were as-metal coated, i.e. no passivation.

Edges protected	*AZ coating*	*AM coating*	*Reduction in corrosion rate*
Yes	50	35	30%
No	105	70	33%

Stage 1 to 5 comparison: The AM coating is harder and less ductile than the AZ coating. For tight bends, this leads to a greater number of microcracks in the coating. Intuitively, this may have an impact on the bend corrosion performance. Stage 1 accelerated testing on unpainted product did not show this, however, for painted product there was a higher propensity for white corrosion product to be visible on tight bends. The differing nature of the corrosion process was highlighted in the comparison to the Stage 2 outdoor assessment; after 9 years exposure in a marine environment, the corrosion level on the bends of the painted product was statistically no different between the AZ and AM coatings. Extended outdoor exposure in Stage 2, assessment of product with tight bends in Stages 3 and 5, and understanding the performance when in contact with brick cleaning acid in Stage 4 allowed confidence to be developed that the observations in the accelerated test were an artefact of the methodology, and do not correspond to the 'real world' performance of the product.

Stage 4: The performance of the AM coating in ponding (with a reduced level of surface discoloration on unpainted product), in concrete (less corrosion at the air-concrete interface), and in overall powder coated performance (reduced corrosion rate of the powder coated product), amongst other areas, has shown a marked improvement, not otherwise apparent in the other types of tests. Assessment of water run-off has furthered the understanding of the overall corrosion mechanisms, and helped with the development of corrosion physical models.

5 CONCLUSION

The development of new metallic coating technology opens opportunities to improve the durability of coated steel in current building applications, create the possibility for the use of coated steel in new building applications, and/or reduce the environmental load of coated steel. In understanding these new technologies, a scale-up approach allows a thorough performance profile to be developed and confidence to be delivered to all stakeholders around the durability in 'real world' applications. The importance of understanding different mechanisms between accelerated and 'real world' performance, interactions with other building components, and unwashed conditions, cannot be overstated.

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