EGGA
GALVANIZING EUROPE

The Importance of the Correct Specification of Metallic Coatings for Steel

White Paper January 2024

Introduction

Steel plays a vital role in our everyday lives. From the bridges we cross and the guard rails that protect us on roads to the high voltage pylons and solar installations that power our homes, hospitals and offices, steel structures are all around us.

The life of these vital structures and components is protected and preserved by galvanizing - an essential finishing process in the prevention of steel corrosion. Galvanized steel is used in a diverse sphere of sectors and industries, from construction to agriculture, and is particularly necessary for structures and components exposed to moisture and adverse weather conditions.

However, the durability and corrosion resistance of steel products depends entirely upon the type of galvanized coating used; the thickness and long-term performance of these coatings has a direct impact on the lifespan and protection quality of steel in a variety of environments. Manufacturers of components used in these diverse applications have long recognised the significant advantages of galvanizing their products after they have been fabricated or manufactured, a method known as 'post-galvanizing'.

Post-galvanizing - sometimes referred to as 'batch galvanizing', 'hot dip galvanizing' or 'general galvanizing' - involves the application of a strongly bonded layer of zinc onto the steel, formed by immersing the fabricated steel product into a bath of molten zinc to produce a relatively thick, tough and abrasion-resistant zinc coating.

Post-galvanized EN ISO 1461 is applied after fabrication of steel conponents to ensure complete coverage of the coating.

Because the zinc coatings involve the metallurgical bonding of zinc to steel, the benefits of post-galvanizing are indisputable; their long life-span can be observed all over the world in electricity transmissions towers, steel-frame buildings, bridge sections and other critical structures which have already seen well over 50 years of service.

The post-galvanizing process is relatively simple, straightforward and closely controlled, so the thickness of the zinc coating formed is regular, predictable and simply specified, as well as being one of the few coatings completely defined by an international standard (EN ISO 1461). As well as having a lower lifetime cost and being environmentally sustainable, post-galvanizing offers by far the greatest resistance to mechanical damage during handling, storage, transport and construction - an important factor where steelwork is to be shipped around the world.

There have, at various points, been a number of initiatives for new zinc coating types, but none have demonstrated the effectiveness and longevity of post-galvanized steel. Electroplated zinc coatings, for example, are relatively thin and have no metallurgical bond between zinc and steel. Thermally-sprayed zinc coatings are not fully-dense and therefore must rely on careful surface preparation for their reliability, while zinc-rich paints have limited protective capability compared to metallic zinc coatings.

However, some steel components can be manufactured using an alternative zinc coating process known as pre-galvanizing, or more commonly 'continuous galvanizing'. This method involves the coating of steels with zinc or zinc alloys in its steel sheet or strip form. The sheet is passed continuously through a bath of molten zinc, and when the product cools, the coating is then mechanically wiped to produce a thin layer of zinc or zinc alloy.

The use of pre-galvanized steel sheets to make components is generally limited to use in indoor or non-aggressive situations, due to the relative thinness of the coating and limited metallurgical bond to the steel. As a point of comparison, the typical thicknesses of post-galvanized coatings tend to be between 55 and 200 microns, while in stark comparison, pre-galvanized coatings, including the recently introduced ZM grades, are typically between 5 and 25 microns in thickness. Coating before fabrication also impacts on the steel's ability to be bent during manufacturing, while the cutting or welding creates uncoated and therefore unprotected areas.

In recent years, however, some steel producers have sought to re-invent the use of pre-galvanized steel sheets by making small additions of aluminium and magnesium to the coating - so-called 'ZM' grades. Producers of ZM grade pre-coated steels have diverted attention away from their thinner coatings and the problems of cutting the pre-coated sheet during fabrication by citing laboratory accelerated testing and short-term exposure tests that can overstate the performance of these types of coating.

It is well-known that these accelerated tests are completely inappropriate for either comparisons between different types of zinc coating or for prediction of real-world life expectancy, and the inclusion of results from these testing methods in commercial information has led to over-stated, inaccurate, confusing and misleading information about the longevity and performance of ZM coatings.

The purpose of this paper, therefore, is to explain why post-galvanizing is the optimal corrosion protection system, and to present an accurate and reliable picture of true performance and life expectancy that will enable end users to make a more informed decision on the most effective protection for their steel products.

In subsequent sections, this paper will 1) correct and clarify claims around the cut edge issue and 'self-healing' effect of pre-coated ZM coatings, 2) deconstruct the use of accelerated testing methods and evaluate their true relevance to corrosion performance, and 3) examine and interrogate the stated evidence on the corrosion behaviour and resistance of each coating type in a range of environments.

Corrosion Risks at Cut Edges

For many decades, post-galvanizing has been widely recognised – and proven – to be the most effective and reliable way to protect steel from corrosion in a variety of industries and outdoor environments, while the use of pre-coated sheet has generally been considered an inferior method of protection more suitable for indoor use, or where product life expectancy was very short.

Because post-galvanizing takes place after a component has already been fabricated, the steel is coated with a tough and abrasion-resistant zinc coating both externally and internally. This means the steel product arrives on site ready for immediate use. No further site surface preparation, painting, touch-up or inspection is necessary, and installation can begin immediately – thus accelerating construction time.

By contrast, since pre-coating takes place before the product has been fabricated, a steel product made in this way will have cut edges that have not been protected, leading to quicker corrosion potential and unsightly red rust around exposed and unprotected areas.

Coating damage is most likely to occur at the edges, where protection is often needed the most. Post-galvanizing overcomes this problem because the process involves complete coverage by total immersion of the product, ensuring that all surfaces, holes, edges and internal areas are covered, including recesses and hard-to-reach corners.

Despite claims to the contrary, the cut edge issue represents a major weakness for use of ZM coatings and, ultimately, means that when specifying this coating type, users can expect to see rust on the cut edges as early as the initial delivery of the product.

The need to provide reassurance to customers on this notable weakness has subsequently led to potentially misleading assertions from ZM suppliers.

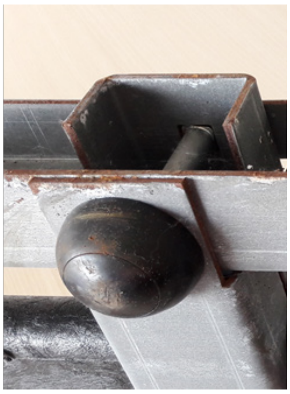
It is claimed, for example, that a "self-healing" effect occurs in ZM coatings due to the formation of a protective film over the surface and that this film will gradually cover and protect the damaged edge or area. Also, assurances are often given that this self-healing effect will occur in all types of natural environments if the underlying steel is cut, perforated or scratched.

However, there are a number of issues to consider alongside these claims - primarily that the initiation speed and duration of the self-healing effect is heavily influenced by the aggressiveness of the environment.

And in the case of limited corrosion, little or no self-healing has been observed in many cases - as shown in **Figure 1** and **Figure 2** which show samples of ZM coated steel with uncoated cut edges after a short exposure period.

Figure 1

Figure 2



Cut edge protection for steel thickness greater than 2mm, where the cathodic effect reduces due to the reduced coating thickness, is especially questionable if the environment is not aggressive enough. Users of ZM coated steels have reported that red rust can still be seen after 25 months on 'self-healed' cut edges on parts situated in rural environments.

Perhaps more concerning is that for ZM steel products in more aggressive environments with a high ratio of cut edges to surface area, the effort of the coating to protect cut edges can lead to actual consumption of the coating. This presents a significant issue in real-case products where most instances of cut edges are unprotected and the overall thickness of the coating is low to begin with.

In their study of corrosion of ZM coatings in a marine environment, Tomandl et al[1]. observed that ZM coatings adjacent to cut edges were completely consumed within three years at a test site in China and just one year at a test site in Mexico (Figure 3). The authors of this paper concluded that: *'...on specimens with a thickness of 2mm, cathodic protection at the cut edges no longer exists after conversion of the layer 2-3mm away from the edge...'* and that, *'...according to this evaluation, long-term protection at the cut edges is to be expected only on the specimens from the location with the lowest corrosivity...'*

Figure 3

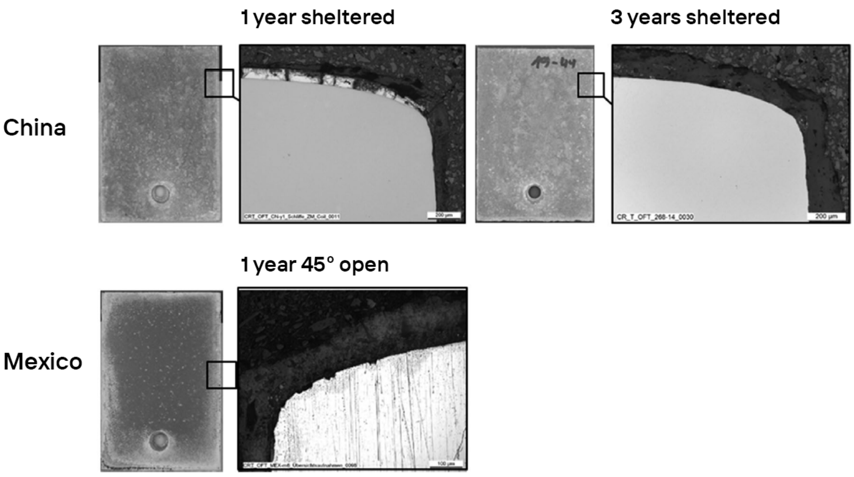
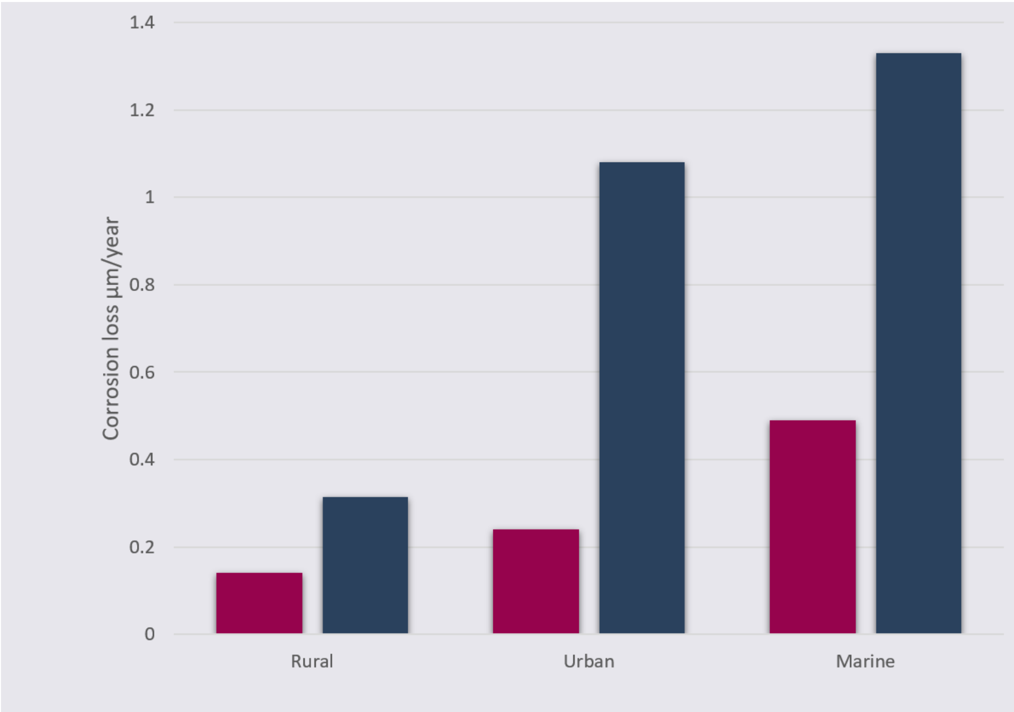


Figure 4

It is clear that unprotected cut edges have a high influence on the corrosion rate of ZM coatings in areas adjacent to the cut edges (**Figure 4**).

These effects are hidden in most of the reported short-term corrosion tests for ZM coatings. Cut edges and the back of the test samples used in outdoor exposure testing are generally protected either by tape or by paint. This method testing avoids any effect of cut edges on the corrosion of the test panel – which is a significant departure from reality for many steel products where ZM coatings may be used. This important effect has been shown in a five-year atmospheric exposure study conducted in Japan that demonstrated the significant difference in corrosion performance when measured with painting of the cut edges and without such painting (**Figure 5**)[2].

Figure 5



	Rural	Urban	Marine
ZM Painted edges	0.14	0.24	0.49
ZM Unpainted edges	0.315	1.08	1.33

A lack of confidence in the claimed self-healing effect may be reflected in the warranties offered for ZM coated steels, which often state that the visual effect and discoloration of the surface due to cut edge run-off are not covered, nor is accidental damage like scratches or dents which require repair.

Misleading Accelerated Testing

The corrosion performance of post-galvanized steel products is extensively documented – based on both field-exposure tests and the experience of products or structures that have been monitored throughout their lifetime. The life of a post-galvanized coating is therefore very predictable and is, quite simply, in direct proportion to its thickness in any given environment.

However, the lack of long-term data on the performance of ZM products in outdoor environments has led suppliers to turn to accelerated testing methods such as the controversial neutral Salt Spray Test. These accelerated tests have been performed as comparisons – despite clear guidance in ISO standards that the tests should never be used to compare or rank the performance of different materials in corrosion resistance, nor as a means of predicting long-term performance.

These tests have no relevance to real service conditions and yet they have been used extensively to promote ZM-coated steels.

Even the smallest variations in test conditions can artificially indicate performance differences between coatings of up to 10 times. This figure has since been exploited to claim that ZM coatings can last almost 10 times longer than conventional zinc coatings products – an assumption that is absolutely incorrect.

The '10 times' performance is only achieved using accelerated testing in environments with an unrealistically high salt concentration. An entirely different result would be obtained by lowering the NaCl concentration in the test, which demonstrates why ISO standards state that such tests should never be used for comparisons between materials.

Looking more closely at this unrealistic testing procedure reveals further information on why these methods are not valid. Samples under test are inserted into a temperature-controlled chamber where a salt-containing solution is sprayed, at 35°C, as a very fine fog mist. As the spray is continuous, the samples are constantly wet, with no cyclic drying. Samples are therefore constantly subject to corrosion, which does not happen in reality, and prevents metals such as zinc from forming a passive film as it would in real situations.

The test can give similarly misleading results when comparing different variants of zinc coatings. For example, small additions of magnesium or aluminium to a zinc coating will produce salt spray test results that differ significantly from real exposure conditions. Magnesium ions promote the formation of protective corrosion products in the presence of the high levels of sodium chloride injected during these tests, thus reducing observed corrosion rates. This explains why ZM coatings show artificially better performance when compared to zinc, in accelerated tests involving continuous wetness and a high chloride load. This will not occur in real situations.

To illustrate this point further, at the direction of EGGA, the French laboratory CETIM conducted an accelerated test on both post-galvanized and ZM-coated steel components. This standard test, originally developed by Volvo, omits chlorides from the test chamber. The results showed that the post-galvanized samples exhibited superior corrosion performance in this test (**Figure 7**). This does not justify the use of accelerated testing for comparison of metallic coatings, but it does illustrate very clearly that the choice of test conditions can reverse outcomes of such tests.

Figure 6

Figure 6: Results of accelerated corrosion testing (in the absence of chlorides) of batch galvanized sample (left) and ZM coated steel (right) after 10 cycles.

Unfortunately, the use of salt spray test results to guide the selection of protective coatings for steel remains a serious problem in the engineering community. Despite the well understood limitations of the test in the 'corrosion sector', it still used to promote the use of coatings with properties that appear to produce favourable results. Despite the attraction of quick and short-term information, there is no substitute for corrosion data generated from long-term exposure testing and case history information from real structures or components in active service.

Corrosion Behaviour and Corrosion Resistance

As explained above, the behaviour of metallic coatings in real conditions differs significantly to their behaviour in accelerated testing, since laboratory conditions never mirror the real environment and specific test conditions may be especially aggressive (or non-aggressive) for certain types of coating.

In reality, varying temperatures, precipitation volumes, humidity levels, pollution loads or distances to sea can all have a decisive effect on overall corrosion behaviour. These are almost impossible to replicate in accelerated testing.

Since accelerated testing has now been accepted as highly misleading when comparing ZM steels with post-galvanized coatings, short-term atmospheric exposure results gathered over just a few years have been used to communicate relative performance. But these studies can also be very misleading if they are extrapolated to indicate longer-term performance. In order to accurately test exposure, one or two years is far from representative of long-term performance.

In tests often cited in promotional documents, corrosion rates for conventional zinc coatings appear to be significantly higher in the first year by comparison. Again, this is not an accurate representation of long-term performance because over subsequent years of exposure, conventional zinc coatings have much lower corrosion rates and remain more stable than ZM coatings, mainly due to patina formation at the surface.

Studies show that, in the early years of testing, zinc corrosion rates are significantly higher in comparison to ZM-coated steel than is the case when a stable corrosion situation has been reached. This is because during the first year of exposure, a zinc coating will not have developed its protective patina. Conversely, the magnesium phase of the ZM coating surface will be depleted in later years, but less so in the earlier years. The most scientifically correct approach would be to discard this first-year data (and probably also the second-year data) in any long-term corrosion test for zinc or zinc alloys and to focus on the later data as a better indication of real performance.

This fact remains undisputed in the corrosion science community and is backed up by a wealth of long-term atmospheric exposure data for post-galvanized coatings. When this fact is ignored, the comparative performance of post-galvanized and ZM coatings is distorted in favour of ZM-coated steels by focusing on the early years of such tests.

A paper by Thierry et al (2019) has described a worldwide exposure test programme and reports results for a 4-year period that have been used in promotional materials from ZM steel producers. Unfortunately, these results include the influence of the first-year and second-year data. However, corrosion rates for individual years are reported in the same paper, allowing the re-calculation of the corrosion rates for hot dip galvanizing and ZM coatings for the more relevant later years of exposure. These calculations indicate that the performance ratio between hot dip galvanizing and ZM-coated steel changes significantly when the comparison is based the last 2 years and not the first 2 years. There is a significant potential to distort long term performance predictions when such studies are not carefully interpreted and communicated.

Batch galvanizing, after manufacture, to EN ISO 1461 ensures complete coverage of a steel component and thickness of zinc coating that is optimal for long-term durability of steel structures.

The exposure programme reported in Thierry et al (2019)[5] also indicates that, as shown in Table 1, for some of the sites the corrosion performance of ZM-coated steels for the last 2 years of testing is very similar to that of zinc coatings.

Table 1: HDG/ZM performance ratio calculated for selected sites from the worldwide exposure program, based on Thierry et al (2019)

Exposure sites	After 1st year	After 2 years	After 4 years	Last 3 years	Last 2 years	Classification
Cadiz	2.4	2.3	1.6	1.4	1.3	Marine/Urban
Kvarnvik	2.5	4.3	2.1	2.0	1.1	Marine
Singapore	2.7	2.5	2.0	1.7	1.5	Marine/Urban
Wanning	2.8	3.2	1.9	1.6	1.1	Marine
Average	**2.6**	**3.07**	**1.9**	**1.67**	**1.25**	

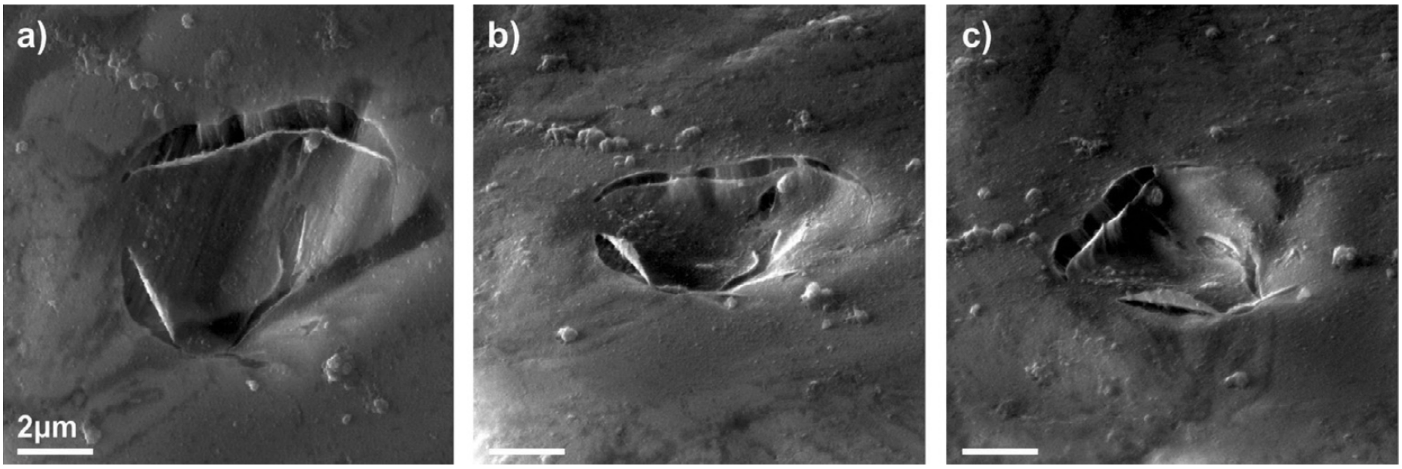
Even after selecting the most relevant data in such exposure studies, another important emerging issue in the evaluation of corrosion behaviour of ZM coated steels is the scientific method used to remove the products of corrosion and therefore to calculate the corrosion losses. Standard procedures now recognise that the laboratory methods used to remove products of corrosion are underestimating these corrosion losses because the method that is most often used for zinc corrosion does not work effectively for ZM steel corrosion. Put simply, the so-called 'glycine method' does not fully remove corrosion products created from the aluminium and magnesium phases of the coating. The most recent version of ISO 8407 (the international standard for methods of removing corrosion products in these tests), has recognised this problem and states that the 'glycine method' is not suitable for assessing corrosion losses for ZM coated steels. This means that the estimations such as those in Table 1 are very likely to underestimate ZM steel corrosion and overestimate its performance compared to post-galvanized coatings.

The unpredictability and uncertainty over the true corrosion performance of ZM-coated steels is mainly due to the differing microstructures associated with the various compositions of zinc, aluminium and magnesium present in these coatings. It is claimed that ZM alloy coatings contain zinc dendrites surrounded by a ternary phase of zinc, aluminium and intermetallic $MgZn_2$, which is more active in the galvanic series than zinc and will preferentially corrode to protect the steel. In reality, there is no uniform corrosion of ZM-coated steel. The magnesium and aluminium-rich boundary zones are preferentially consumed. In areas with defects or in non-uniform areas, there is an extremely high risk of pitting attack and complete coating consumption.

In the short term, the boundaries zones (rich in magnesium and aluminium) are attacked, followed by the zinc-rich grains. This fact is supported by the EDS maps which demonstrate a severe depletion of magnesium and zinc on the surfaces. Data gathered in the DURADH RFCS Project revealed a continuous decline in impedance value over time, indicating progress dissolution of the oxide coating and the pit-like corrosion of the alloy containing magnesium.

Figure 7 shows scanning electron images at different tilt and azimuth angles, of a formed corrosion pit which is still covered by a thin layer of the original ZM coating surface. In contrast, the corrosion process for post-galvanized steel is relatively stable and uniform over time.

Figure 7



Corrosion in Specific Environments

Tunnels

In a project for the Stockholm Bypass (Förbifart Stockholm), Swerea KIMAB[8] assisted the Swedish Transport Administration (Trafikverket) with the elaboration of corrosion-related requirements on materials and coatings for use in road tunnels.

Results of tests carried out are shown in **Figure 8** and **Figure 9**.

Figure 8

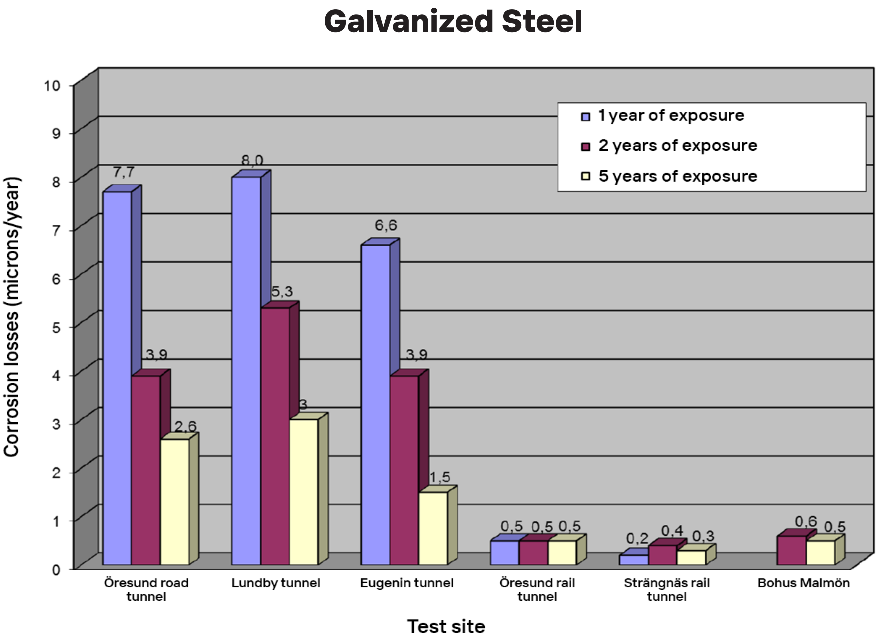
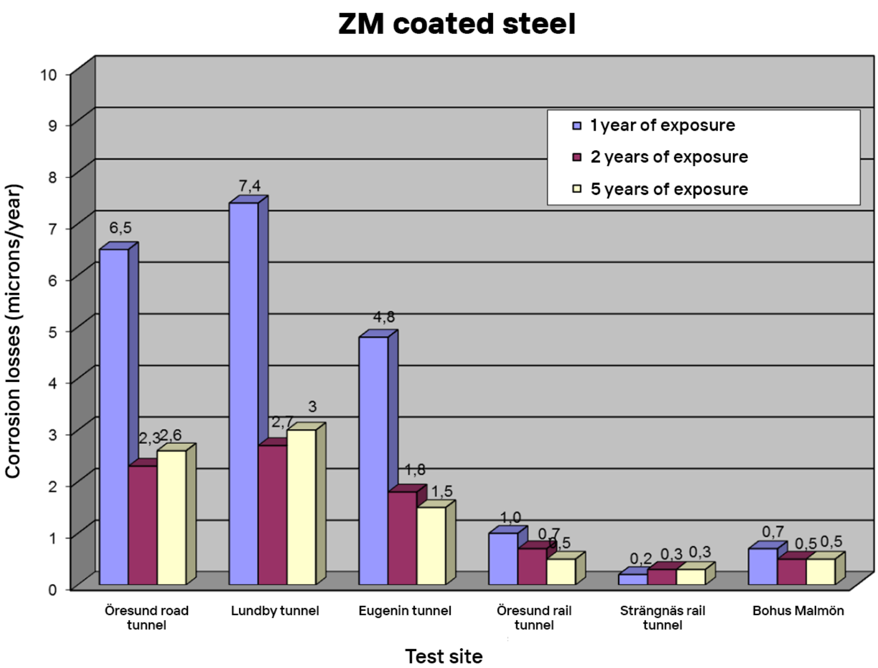


Figure 9



These tests showed no significant difference in the corrosion rate of zinc (galvanized) and ZM-coated steels. The expected coating performance would therefore be determined by the coating thickness as shown in Table 2.

Table 2

Microns/yr based on 5 yr exposure	Road Tunnel 1	Road Tunnel 2	Road Tunnel 3
Galvanized	2.6	3.0	1.5
ZM Steel	2.6	3.0	1.5
Expected life (yrs) Galvanized (85 microns)	33	28	57
Expected life (yrs) ZM 310 (24 microns)	9	8	16

Confined and Overlapping Spaces

The metal loss in conventional zinc coatings on products in confined spaces - or with overlapping surfaces - is approximately two times higher compared to open exposure. However, this ratio has been shown to be significantly higher for ZM coatings, which have shown a metal loss up to 12 times higher in the same circumstances. This is illustrated in **Figure 10**.

In a similar test on the performance of coatings in confined situations (referred to below in Figure 11 as 'hem-flange'), ZM coatings lost four microns in two years, out of a total of seven microns.

Figure 10

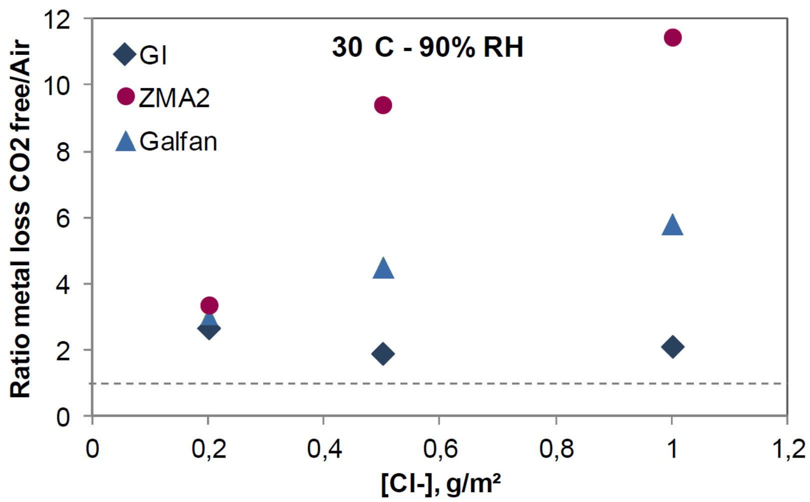
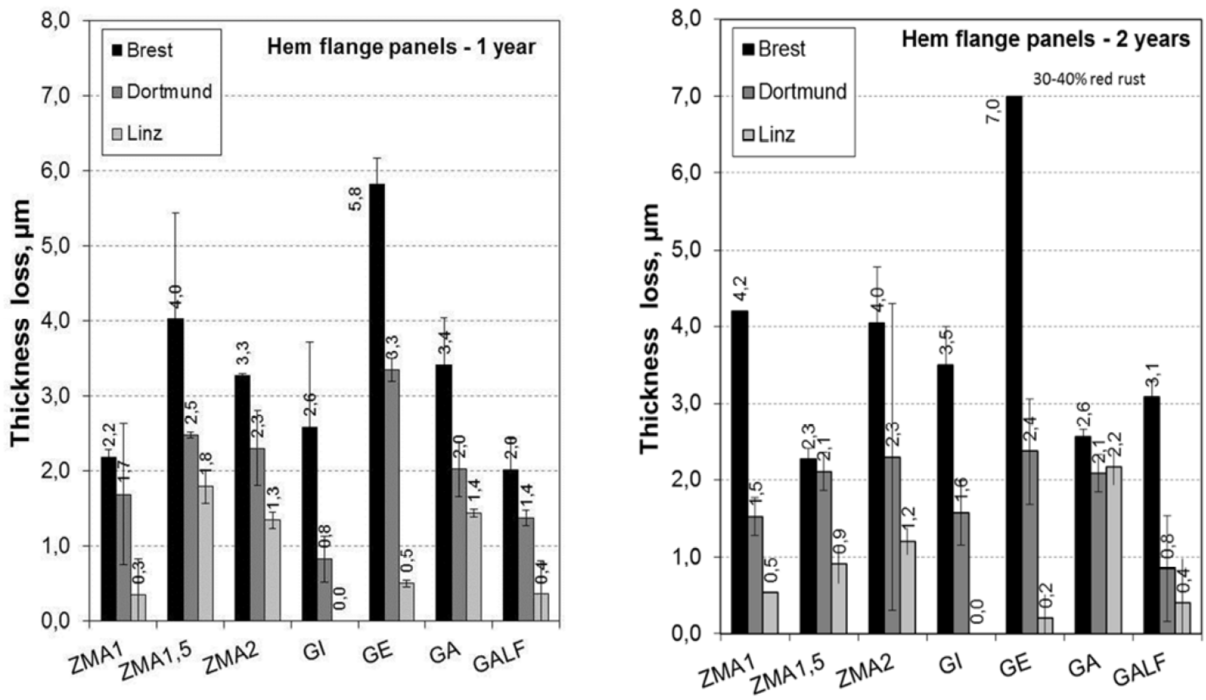


Figure 11



Contact with Concrete

The performance of ZM coatings in concrete has also been overstated based on testing in laboratories. An example of an unrepresentative test of corrosion behaviour in concrete is one in which a low coating thickness was chosen for comparison (20 microns) and in a high alkalinity solution over 12 weeks of laboratory testing. In reality, any high alkalinity of concrete is only present in the first 24-48 hours until the concrete hardens, then the pH changes.

When we look at the behaviour of conventional zinc coatings in concrete, we can see that a small part of the coating is consumed during the first few hours until the concrete hardens, but the remaining coating is more than sufficient to provide long-term protection. In the case of ZM coatings, however, the low initial coating thickness means that the remaining thickness may be insufficient for long-term protection.

Abrasion Resistance in Desert Environments

Short-term (two-year) tests have been cited in which the abrasion of a post-galvanized coating is higher compared to a ZM coating. Post-galvanized coatings are well-known for their high levels of abrasion resistance due to the hard, compact iron-zinc alloy layers in the coating. These iron-zinc alloy layers sit just beneath a softer outer layer of zinc. In a short-term test, the abrasion resistance iron-zinc alloy layers are unlikely to have been exposed and their long-term contribution to abrasion resistance will go unnoticed over a limited two-year period. Once again, a short-term test provides misleading indication of the long-term performance.

Interestingly, it has been reported that short-term tests of ZM steels in desert environments have shown unusually high ‘corrosion’ losses during periods that include significant sand-storm events. This has been attributed to the relatively soft ZM coating.

Agricultural Environments

Short-term tests on ZM steels to assess corrosion performance in animal housing environments have been cited in promotional documents for ZM steels. The tests have been carried out in a ‘basic’ environment with a pH level of 11.7. However, the pH environment created by animal waste differs significantly to these assumptions and is much closer to an acidic environment in which ZM coatings would not perform differently.

Additionally, these tests were conducted over a period of just 24 hours, well before post-galvanized coatings would have been able to create a protective patina.

Forming

The forming of ZM-coated steels also brings complications. ZM coatings currently offer inferior formability in comparison with conventional zinc-coated steels, because brittle phases within ZM coatings can lead to cracking in severely deformed regions.

This would result in the formation of corrosion products - as well as further degradation of corrosion resistance once the cracks develop a large opening - and would mean that geometry and surface of forming tools would need to be adjusted to the material to compensate. **Figure 12** illustrates these issues in greater detail.

Figure 12

Effect of forming on ZM coated steels

Zn-Al-Mg coating after bending through 2 x section thickness

Source: Nisshin Steel, Galvatech 2011

Zn-Ai-Mg coating after 180° bending (without mandrel)

Source: CENIM, Spain

Zn-Ai-Mg coating at formed area of typical highway guard rail

Source: CENIM, Spain

Schuerz[10] et al showed that at a level of 5% plastic deformation, cracks are visible on the surface and in a ZM coating. At 10% deformation, the cracks pass through the coating and reach the substrate. The length and opening of these cracks increase with the deformation grade and are associated with the presence of the fragile $MgZn_2$ intermetallic phase in ZM coatings.

Zunko[11] et al studied the effect of different deformation levels (stepwise stretching) on three different ZM coating thicknesses of 7, 15 and 24 µm. If the formation of further cracks with increasing elongation is favoured on the thinner coatings (microcrack density on 7 and 15 µm coatings increased as the strain rate increased), on thicker coatings on the other hand there is no new formation of cracks within the strain range observed but the average width of the microcracks increases with increasing elongation. Figure 13 shows images of the surface of the sample with a 24 µm coating at 7% elongation (a) and at 27% elongation (b). It can be observed that the average width of the microcracks and the proportion of open areas increases with increasing elongation.

Figure 13

Fig 13a : Surface image of sample 3 at 7% elongation

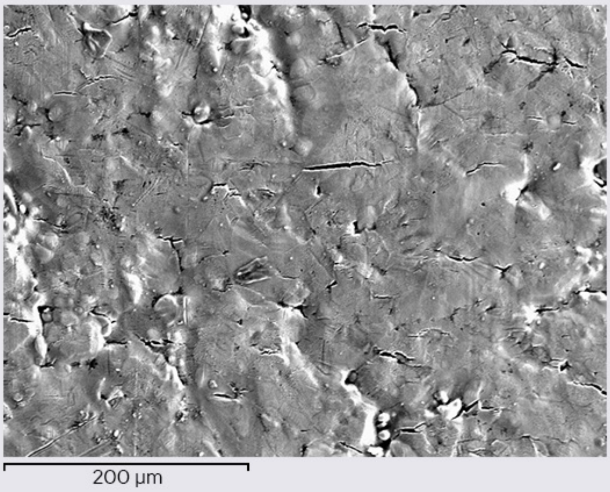
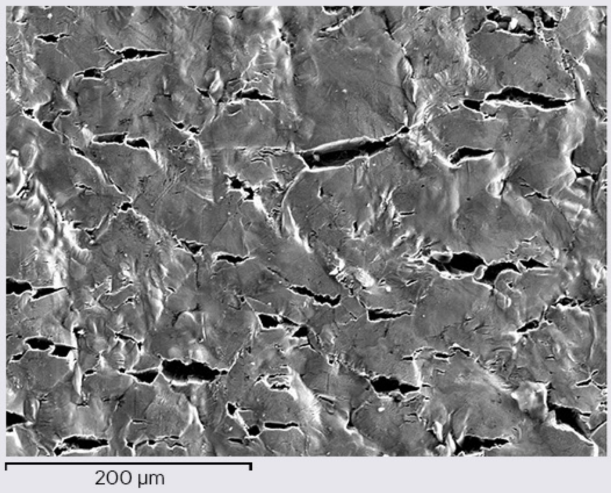


Fig 13b : Surface image of sample 3 at 27% elongation



Summary

This document has extensively examined and evaluated numerous tests, data, research and commercial information from those representing the post-galvanizing industry, as well as information that is used to promote the use of ZM coatings.

We have outlined the numerous proven benefits of post-galvanized zinc coatings and carefully deconstructed the numerous claims made for ZM-coated steels in order to clarify and correct commercial information which has, for some time, been potentially misleading and confusing to end users.

Having evaluated this evidence, it is irrefutably clear that the performance, behaviour, life span and corrosion resistance of post-galvanized coatings – in a diverse range of conditions - is superior to pre-coated steel sheets – even when coated with the latest range of ZM coatings.

Promoting transparency and reliability throughout all the research and testing processes used to evaluate coating performance is a critical part of our overall mission. The aim of the post-galvanizing industry is to ensure specifiers and end users have access to honest, accurate, proven and comprehensive information in order to make a fully informed decision about the coatings which are most suitable for their steel products and specific environments.

The post-galvanizing industry is committed to ensuring a bright future for the lifetime of steel products, and we will continue to champion post-galvanized steel as a proven, reliable and sustainable protection for any environment.

EN ISO 1461

References

Figure 1	Associazione Italiana Zincatura, Italy
Figure 2	Galvazinc, France
Figure 3	Reference 1, Figure 9, page 1291
Figure 4	Reference 1, Figure 10, page 1291
Figure 5	Japan Galvanizers Association (Reference 2)
Figure 6	EGGA-CETIM study results
Figure 7	Reference 7, Figure 6, page 331
Figure 8	Reference 8, Figure 45, page 51
Figure 9	Reference 8, Figure 46, page 52
Figure 10	Reference 3, Figure 73, page 83
Figure 11	Reference 3, Figure 36, page 47
Figure 12	Reference 9, Fact 4
Figure 13	Reference 11, Figures 8, 9 17, 18, 19, Pages 338 and 340

References

1. A. Tomandl, E. Labrenz, The corrosion behavior of ZnAlMg alloys in maritime Environments, Materials and Corrosion 2016, 67, No. 12, p. 1286

2. H. Shibayama, Y. Takedomi, Comparative performance of galvanizing with continuously applied Zn-Al-Mg coatings. Results of exposure tests in Japan, 24th International Galvanizing Conference Intergalva, Liverpool, 2015

3. European Commission, EUR 26323 — Advanced zinc-based hot dip coatings for the automotive application (AUTOCOAT), Publications Office of the European Union, ISBN 978-92-79-34587-6, Luxembourg, 2013

4. Research report VOLVO VCS 1027:33719 (2005) Climate ageing test for various zinc and zinc alloy coatings (CET0144715_PV_FINAL_01_b_EN), CETIM, 2017

5. D. Thierry, D. Person, G. Luckeneder, K.H. Stellnberger, Atmospheric corrosion of ZnAlMg coated steel during long term atmospheric weathering at different worldwide exposure sites, Corrosion Science, Volume 148, 2019, Pages 338-354, ISSN 0010-938X

6. European Commission, EUR 27718 - Durability of adhesively bonded surfaces finished galvanised steels in corrosive environments (DURADH), Publications Office of the European Union, ISBN 978-92-79-54690-7, Luxembourg, 2014

7. J. Duchoslav, M. Arndt, R. Steinberger, T. Keppert, G. Luckeneder, K.H. Stellnberger, J. Hagler, C.K. Riener, G. Angeli, D. Stifter, Nanoscopic view on the initial stages of corrosion of hot dip galvanized Zn–Mg–Al coatings, Corrosion Science, Volume 83, 2014, 327–334

8. Research report Corrosion and corrosion protection of metallic materials in tunnels (KIMAB-2014-113), KIMAB, 2014

9. Technical Factsheet Batch hot dip galvanizing and continuously coated ZM grade steels – a true comparison, EGGA, 2013

10. Susanne Schürz, Korrosionsverhalten von Zn-Al-Mg-beschichtetem Stahlband, PhD thesis, Montanuniversität Leoben, 2010

11. H. Zunko, A. Hackl, H. Antrekowitsch, R. Ebner, R. Brisberger, F. Priewasser, C.K. Riener, Analyse des Umformverhaltens von Zn-Al-Mg-Beschichtungen, Springer-Verlag, BHM, 154. Jg. (2009), Heft 7, 334-341

12. Commercial brochure, PosMAC® 3.0 POSCO Magnesium Aluminium alloy Coating product, Published August 2018

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