1. Metallic-Coated Products and Specifications	
GalvInfoNote 1.11	**Zinc-Aluminum-Magnesium Alloy-Coated Steel Sheet** **REV 1.2 August 31, 2026**

Summary

This note provides a concise technical overview of continuously hot-dip Zn-Al-Mg alloy-coated steel sheet, including coating families, microstructure, corrosion mechanisms, cut-edge protection, forming, joining, typical applications, and selection considerations.

Zn-Al-Mg is intentionally treated as a coating family rather than a single alloy. Quantitative performance claims are linked to cited test conditions, and no universal corrosion-life multiplier relative to conventional GI is proposed.

1. Introduction

Zinc-aluminum-magnesium (Zn-Al-Mg) alloy-coated steel sheet is a family of continuously hot-dip coated products developed to provide enhanced corrosion resistance compared with conventional zinc-coated, or galvanized (GI), steel sheet. The coatings combine the sacrificial protection of zinc with changes in coating microstructure and corrosion-product chemistry introduced by Al and Mg additions [1,4-8,16,17].

The term Zn-Al-Mg does not describe one unique composition. Commercial products and ASTM A1046/A1046M cover a broad range of Al and Mg concentrations, with zinc forming the balance in the alloy composition [1]. This compositional breadth is central to understanding the technology: phase constitution, solidification morphology, corrosion behavior, forming response, and joining characteristics can differ materially among products [13-17].

Zn-Al-Mg coated sheet is used in building and construction, automotive components, solar mounting systems, agricultural structures, electrical enclosures, infrastructure, HVAC equipment, and other applications in which corrosion durability, exposed cut-edge performance, or coating-mass efficiency is important [12,16,17].

2. Coating Composition and Specifications

ASTM A1046/A1046M-25a is the active ASTM specification for steel sheet coated by the hot-dip process with Zn-Al-Mg alloy. It covers steel sheet in coils and cut lengths intended for applications requiring corrosion resistance and paintability [1].

The current ASTM framework recognizes 7 coating-bath composition types. Across those types, the bath compositions span approximately 0.5 to 21 wt.% Al and 0.4 to 8 wt.% Mg, with up to 1 wt.% total additional alloying elements (excluding iron) and the balance zinc [1].

Table 1. Zn-Al-Mg coating-bath composition types in ASTM A1046/A1046M-25a [1].

ASTM coating type	Aluminum, wt.%	Magnesium, wt.%
Type 1	5 to 13	2 to 4
Type 2	3 to <5	2 to 4
Type 3	3 to 6	0.4 to <2
Type 4	0.5 to <3	0.4 to <2.6

ASTM coating type	Aluminum, wt.%	Magnesium, wt.%
Type 5	0.5 to <3	2.6 to 4
Type 6	10 to 14	>4 to 6
Type 7	17 to 21	4 to 8

2.1. Composition–Microstructure Relationship in the Zn-Al-Mg Ternary System

The ternary Zn-Al-Mg phase diagram helps explain why coatings within the broad ASTM A1046 composition range can develop very different solidification structures. At approximately 3 wt.% Mg, moving from low Al toward higher Al changes the solidification path and the balance among primary Zn-rich phase, Al-rich phase, $MgZn_2$-containing constituents, and Zn/Al/$MgZn_2$ ternary eutectic. Thermodynamic and microstructural studies of the Zn-rich corner show that low-Al compositions tend to retain a larger fraction of primary Zn with eutectic constituents concentrated between Zn-rich regions, while increasing Al increases the participation of Al-rich and ternary-eutectic constituents [18,19].

Industrial hot-dip coatings solidify rapidly and therefore do not always follow the equilibrium phase diagram exactly. In particular, metastable $MgZn_2$ can be observed where equilibrium calculations predict Mg_2Zn_{11}. The composition–microstructure comparison on the supplied slide is attributed there to Su Dinh N. et al. [20]; because the bibliographic entry shown on the slide could not be reconciled with the published contents of the cited journal issue, the technical interpretation used here is cross-supported by independently verifiable sources [18,19].

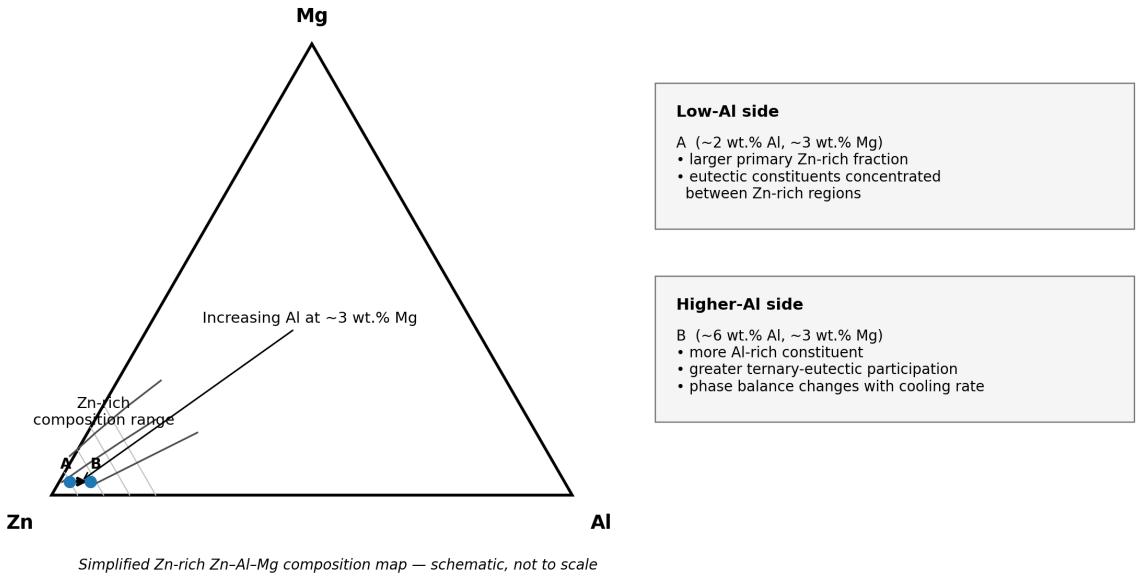

Figure 1. Simplified Zn-rich Zn-Al-Mg ternary composition map illustrating a change from low Al to higher Al at approximately 3 wt.% Mg. The diagram is a schematic redraw for this note and is not a quantitative equilibrium phase diagram [18,19].

Representative composition–microstructure trend at approximately constant Mg

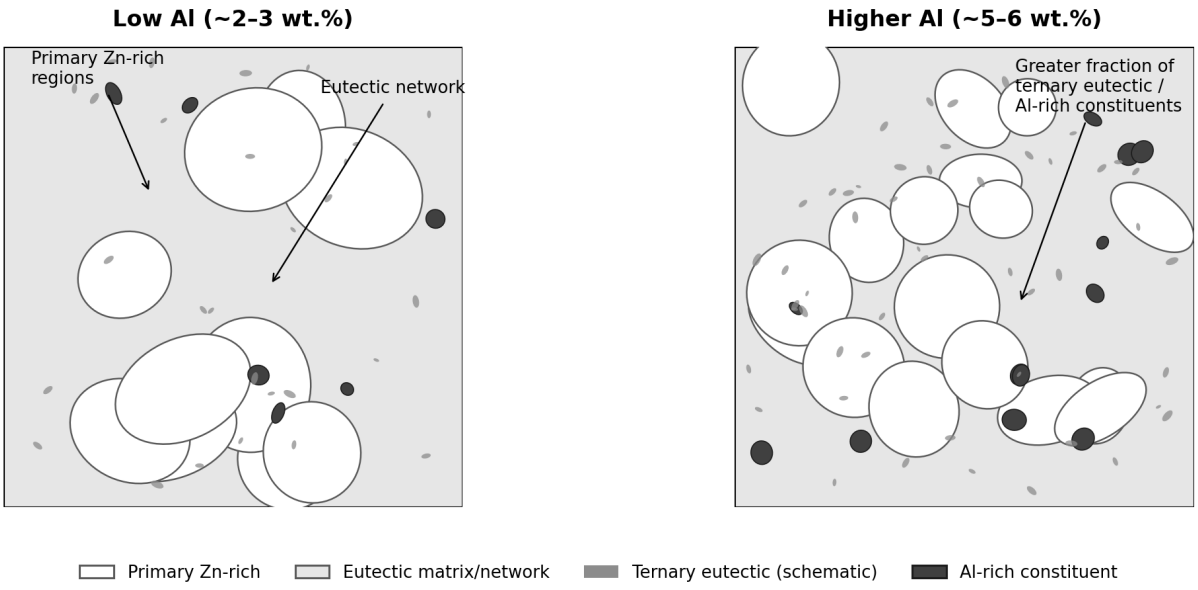

Figure 2. Schematic comparison of representative low-Al and higher-Al Zn-Al-Mg microstructures at approximately constant Mg. Increasing Al changes the relative amounts and morphology of primary Zn-rich, Al-rich, and eutectic constituents; actual phase fractions depend on composition and solidification history [18,19].

Coating designations are expressed as the minimum total coating weight or mass on both surfaces. GalvInfo Note 1.1 provides additional guidance on interpreting coating weight/mass designations and coating thickness for zinc-based sheet products [2].

For example:

• ZM60 indicates a minimum total coating weight of 0.60 oz/ft^2 on both sides.

• ZMM180 = 180 g/m^2 minimum total coating mass on both sides.

It is important to distinguish this ASTM terminology from European practice. EN 10346 uses the designation ZM for zinc-magnesium alloy-coated sheet, followed by a coating-mass designation [3].

Because coating density and phase constitution vary with Al and Mg content, identical coating mass does not necessarily imply identical coating thickness or performance across different Zn-Al-Mg chemistries [1,2,16,17].

2.2. Important: Zn-Al-Mg is not one coating

ASTM A1046/A1046M-25a encompasses seven alloy families across a wide Al-Mg composition window [1]. A Zn-Al-Mg result obtained for one bath chemistry should not automatically be applied quantitatively to another.

Coating composition, coating mass, solidification history, substrate, forming strain, joining process, and service environment must be considered together when interpreting corrosion or mechanical performance [13-17].

3. Coating Microstructure

The corrosion and mechanical behavior of Zn-Al-Mg coatings is closely related to their multiphase microstructure.

Depending on alloy composition and cooling conditions, typical Zn-Al-Mg coatings may contain:

- primary Zn-rich dendrites or grains;
- Zn-$MgZn_2$ binary eutectic regions;

- Zn-Al-Mg ternary eutectic regions containing Zn, Al-rich constituents and $MgZn_2$;
- interfacial Al-Fe-containing phases adjacent to the steel substrate.

Higher-Al commercial Zn-Al-Mg products may exhibit somewhat different phase distributions, but $MgZn_2$ and Zn-rich phases remain important constituents in many commonly used coating compositions [4,6,13,16,17].

Unlike essentially single-phase conventional GI coatings, Zn-Al-Mg coatings therefore contain microscopic regions with different electrochemical potentials.

The Mg-containing phases, particularly $MgZn_2$, are generally more electrochemically active than the primary Zn-rich phase and can preferentially dissolve during the initial stages of corrosion.

This preferential dissolution is an important part of the mechanism responsible for the subsequent formation of protective corrosion products [13].

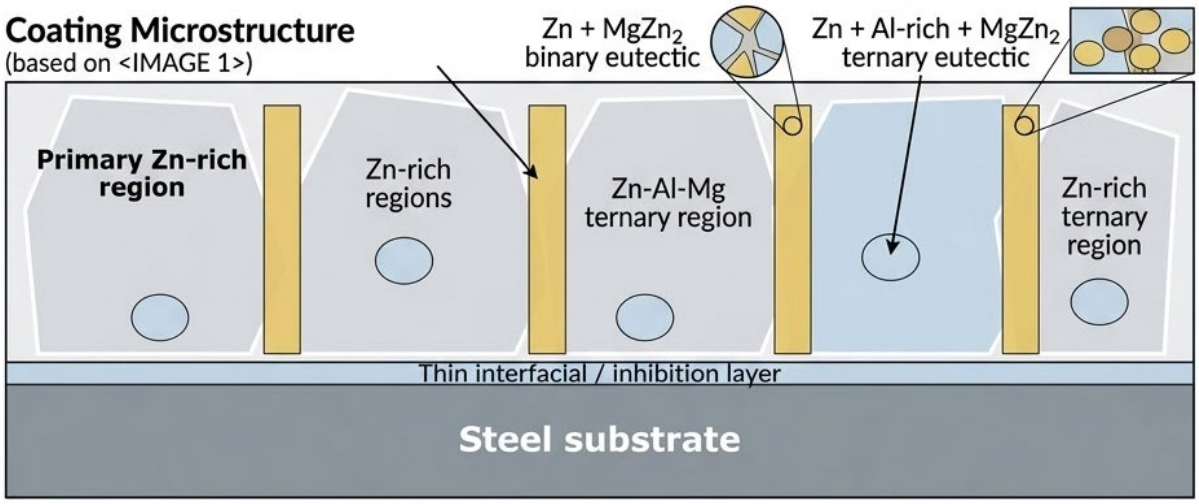

Figure 3. Representative schematic microstructure of a Zn-Al-Mg coating. The identity, morphology and volume fraction of Zn-rich, $MgZn_2$-containing and Al-containing phases vary with composition and solidification conditions [4,6,13,16,17].

4. Corrosion Protection Mechanisms

4.1. Why does Magnesium improve Corrosion Resistance

The superior corrosion performance of Zn-Al-Mg coatings cannot be attributed simply to magnesium being inherently more corrosion resistant than zinc. In fact, Mg-rich phases are highly active electrochemically.

The principal benefit of Mg is its effect on the **chemistry, morphology and stability of the corrosion products formed on the surface**.

During atmospheric corrosion, conventional zinc can form products including:

- zinc hydroxide;
- zinc oxide;
- hydrozincite, $Zn_5(CO_3)_2(OH)_6$;
- simonkolleite, $Zn_5(OH)_8Cl_2{\cdot}H_2O$;
- zinc hydroxy-sulfate compounds.

Some of these products provide substantially better barrier properties than others.

Studies of Zn-Al-Mg coatings show that Mg can modify local pH conditions and promote or stabilize relatively compact Zn-containing corrosion products. Mg-containing species can also suppress cathodic oxygen-reduction reactions [4,6,13,16,17].

In model atmospheric conditions, Prosek et al. reported that Al and Mg alloying reduced coating mass loss by factors of approximately four to seven compared with HDG for the specific materials and exposure conditions investigated [6]. This result is important mechanistically but should not be interpreted as a universal field-service-life multiplier.

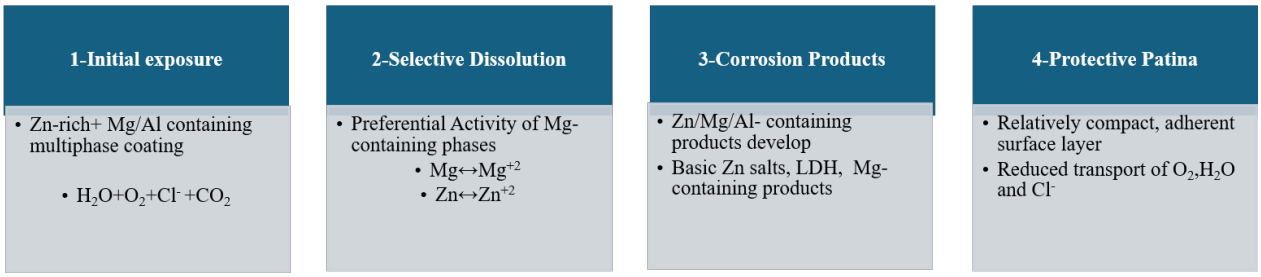

Figure 4. Simplified corrosion protection mechanism for Zn-Al-Mg coatings. Preferential activity of Mg-containing phases, together with Al- and Mg-modified corrosion products, can promote a relatively protective patina. The exact mechanism depends strongly on coating composition and exposure conditions [4-9,16,17].

4.2. Role of Aluminum

Aluminum also contributes significantly to the improved durability of Zn-Al-Mg coatings. In addition to influencing solidification and microstructure, Al can form relatively stable corrosion products, including layered double hydroxide (LDH) phases. One compound reported in Zn-Al-Mg corrosion layers is a zinc-aluminum carbonate hydroxide of the general form:

$$Zn_6Al_2(CO_3)(OH)_{16}{\cdot}4H_2O$$

Schürz et al. associated the improved corrosion resistance of a Zn-Al-Mg coating in salt-spray exposure with the formation of a stable and adherent Zn-Al carbonate-hydroxide-containing corrosion layer [4].

Other studies indicate that the corrosion mechanism is more complex and that no single corrosion product explains the performance under all conditions. Mg-modified zinc salts, LDHs, hydroxycarbonates and other compounds can contribute depending on chloride concentration, CO_2 concentration, humidity, wet/dry cycling and other environmental factors [5]. This distinction is important when interpreting accelerated corrosion tests.

5. Corrosion Performance

Numerous laboratory and field studies have demonstrated improved corrosion resistance of Zn-Al-Mg coatings compared with conventional hot-dip galvanized coatings.

Neutral salt spray testing has sometimes produced very large differences, with Zn-Al-Mg coatings showing several times longer times to red rust than GI. Literature surveys report improvements ranging from approximately four to twenty times in certain neutral salt spray configurations [7-9,14].

However, such values should **not** be interpreted as universal service-life multipliers. The relative performance of Zn-Al-Mg and conventional zinc coatings depends strongly on:

- alloy composition;
- coating thickness;
- coating microstructure;
- chloride deposition;
- atmospheric CO_2;
- wet/dry cycling;

- temperature;
- pH;
- pollutants;
- degree of sheltering;
- presence of paint or other organic coatings.

Research comparing accelerated corrosion tests with natural atmospheric exposure has shown that changes in electrolyte composition can alter both the corrosion products and the relative corrosion rates of Zn and Zn-Al-Mg coatings [16].

Consequently, cyclic corrosion testing and outdoor exposure data representative of the intended application are generally more useful for predicting field performance than neutral salt spray results alone.

5.1. Influence of CO_2 and Exposure Environment

Atmospheric carbon dioxide plays an important role in Zn-Al-Mg corrosion chemistries. LeBozec and co-workers found that reducing atmospheric CO_2 concentration significantly changed the corrosion behavior of Zn-Mg-Al coatings, and their relative advantage over GI was reduced under low-CO_2 conditions [9].

This observation illustrates an important principle: *The corrosion performance of a Zn-Al-Mg coating is a property of the coating/environment system rather than simply a property of the alloy composition*. It is therefore inappropriate to specify a single universal Zn-Al-Mg/GI corrosion-resistance ratio.

6. Cut-Edge Protection

One of the most important properties of Zn-Al-Mg-coated sheet is its ability to protect exposed steel at cut edges.

When a coated sheet is sheared, punched or drilled, the steel substrate is locally exposed. As with conventional galvanized steel, zinc in the surrounding coating can provide sacrificial cathodic protection to the steel.

Zn-Al-Mg coatings provide an additional benefit. Dissolved Zn- and Mg-containing species can migrate toward the exposed cut edge and precipitate as corrosion products. These deposits can progressively cover part of the exposed steel and reduce the electrochemical activity of the cut edge.

Studies of Zn-Al-Mg cut edges have identified combinations of $Mg(OH)_2$, zinc hydroxycarbonates, and simonkolleite associated with this protective process [10].

Improved cut-edge performance has been demonstrated in both laboratory and outdoor exposures. For painted Zn-Mg(-Al) coated material, Mg and Al alloying has also been shown to reduce paint delamination and red-rust development at exposed edges compared with conventional HDG under a number of test conditions.

The commonly used commercial terms “self-healing” or “enhanced cut-edge protection” should nevertheless be interpreted carefully. The metallic coating does not regenerate across the cut edge. Rather, the exposed steel can

become partially protected by sacrificial action and the formation and deposition of corrosion products derived from the adjacent coating.

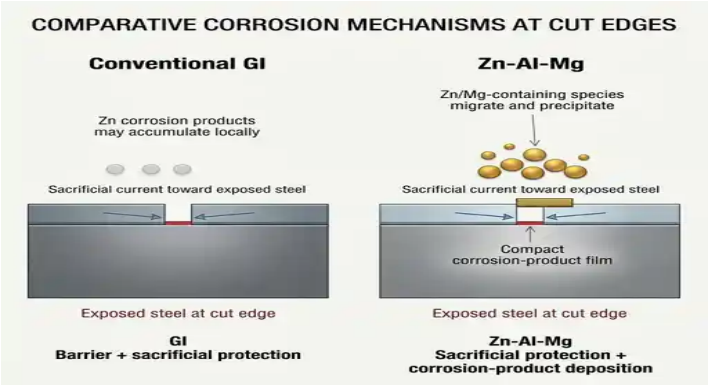

Figure 5. Schematic comparison of conventional GI and Zn-Al-Mg cut-edge protection. Both systems provide sacrificial protection; Zn-Al-Mg can additionally benefit from precipitation of Zn/Mg-containing corrosion products on or near the exposed steel [10,11].

7. Forming, Coating Cracking and Microstructural Effects

Zn-Al-Mg coatings can have excellent processing characteristics, but their mechanical behavior differs from conventional zinc coatings.

$MgZn_2$-containing eutectic constituents are considerably harder and more brittle than the Zn-rich matrix. As a result, Zn-Al-Mg coatings can develop microcracks during bending, stamping, roll forming and other high-strain forming operations.

Recent work has shown that coating chemistry, coating thickness, eutectic volume fraction and substrate deformation all influence crack formation [14].

Malla et al. reported in 2026 that formed Zn-Mg-Al coatings exhibited more extensive cracking than GI under the bending conditions investigated. A heavier 310 g/m^2 ZMA coating contained a larger eutectic fraction and showed substantially greater crack area than an 80 g/m^2 ZMA coating. The deformation also increased the short-term corrosion rate compared with the undeformed condition [15].

This does not mean that Zn-Al-Mg coatings are unsuitable for forming. It does, however, show that **flat-panel corrosion performance alone should not be used to assess a coating intended for highly formed components**.

Coating composition, coating mass, steel grade, lubrication, tool geometry and strain severity should therefore be considered when selecting Zn-Al-Mg coated sheet for demanding forming applications.

8. Painted Systems, Welding and Joining

Zn-Al-Mg coated steels can be used as substrates for painted and coil-coated products.

As with GI and other metallic-coated substrates, satisfactory performance depends upon appropriate:

- cleaning;
- pretreatment;
- conversion coating;
- primer;
- paint chemistry;
- curing conditions.

Improved metallic-coating corrosion resistance can be beneficial when paint defects expose the substrate or when cut edges remain unpainted.

Studies of coil-coated Zn-Mg and Zn-Al-Mg materials have demonstrated reductions in paint delamination and cut-edge red rust under a range of climatic and accelerated test conditions. However, performance depends upon both the metallic coating and the complete paint system [11].

Zn-Al-Mg coated steel can generally be welded and mechanically joined using processes employed for other metallic-coated steels, but process conditions may require optimization.

The presence of Al, Mg and multiphase eutectic constituents changes the melting and vaporization behavior of the coating compared with conventional GI. Resistance spot welding, laser welding, arc welding and adhesive joining should therefore be validated for the specific coating composition and coating mass being used.

As with conventional galvanized sheet, welding locally destroys or modifies the metallic coating and may reduce corrosion protection around the joint unless the design, joining process or supplementary corrosion protection compensates for this loss.

9. Selecting a Zn-Al-Mg Coating

The designation "ZM" or "Zn-Al-Mg" alone is insufficient to define expected field performance. Selection should consider the following variables [1,13-17]:

- Coating chemistry - Al and Mg contents determine phase constitution and influence electrochemical behavior and corrosion-product formation.
- Coating mass - affects the available sacrificial-metal reservoir, coating thickness, microstructure and, for some chemistries, deformation response.
- Steel substrate - strength and ductility influence the strain imposed on the coating during forming.
- Manufacturing operation - bending, roll forming, stamping, punching and shearing create different strain states and exposed edges.
- Exposure environment - chloride, CO_2, humidity, temperature, pollutants, wet/dry cycling and sheltering can change corrosion mechanisms.
- Joining method - welding, fastening and adhesive bonding locally change the coating or create confined geometries.
- Organic coating system - pretreatment and paint chemistry are part of the overall corrosion-protection system.

10. Typical Applications

Zn-Al-Mg coated sheet is used in applications including roofing and cladding components, purlins, solar-panel support systems, cable trays, guardrails, agricultural structures, automotive components, HVAC equipment, electrical cabinets, fencing and storage systems [12,16,17].

The technology is particularly attractive where enhanced atmospheric and cut-edge durability can extend component life or permit optimized coating mass. Any coating-mass reduction should be validated against the required design life and actual service environment rather than based on a single laboratory-test conversion factor.

11. Final remarks

1. Zn-Al-Mg is a family of alloy coatings rather than one specific composition. ASTM A1046/A1046M-25a recognizes seven bath-composition types spanning a broad Al-Mg range [1].

2. The coatings retain the fundamental sacrificial protection mechanism of zinc while using Al and Mg to modify microstructure, local electrochemistry and corrosion-product stability [4-8].

3. Mg-containing phases can dissolve preferentially during early corrosion. Mg and Al can stabilize protective basic zinc salts and LDH-containing corrosion layers and inhibit development of less-protective products under suitable conditions [4-8].

4. Enhanced cut-edge behavior is an important attribute. In addition to sacrificial action, Zn/Mg-containing corrosion products can precipitate on exposed steel and reduce local corrosion activity [10,11].

5. The term "self-healing" should be used cautiously because the metallic coating does not regenerate. "Enhanced cut-edge protection through sacrificial action and corrosion-product deposition" is more technically precise.

6. Corrosion performance is strongly environment- and test-dependent. Neutral salt spray and other accelerated tests should not be translated directly into universal field-service-life multipliers [7,9].

7. Microstructure matters. Cooling history and alloy chemistry alter phase distribution, eutectic fraction and electrochemical behavior and can materially affect corrosion resistance [13,16,17].

8. Formability must be considered. $MgZn_2$-containing eutectic constituents can increase cracking susceptibility under severe deformation, and corrosion qualification after representative forming is advisable for demanding components [14,15].

9. Lower coating mass may be technically feasible for some applications, but the appropriate substitution ratio must be supported by product- and environment-specific evidence [12].

10. Coating chemistry, coating mass, substrate, component geometry, forming, joining, paint system and service environment should be treated as one performance system.

12. References

[1] ASTM International. ASTM A1046/A1046M-25a, Standard Specification for Steel Sheet, Zinc-Aluminum-Magnesium Alloy-Coated by the Hot-Dip Process. ASTM International, West Conshohocken, PA, 2025. DOI: 10.1520/A1046_A1046M-25A.

[2] GalvInfo Center. GalvInfoNote 1.1, Understanding Coating Weight Designations for Zinc-Based Coatings on Steel Sheet. Rev. 4.0, December 2020.

[3] EN 10346:2015. Continuously Hot-Dip Coated Steel Flat Products for Cold Forming - Technical Delivery Conditions.

[4] Schürz, S.; Luckeneder, G.H.; Fleischanderl, M.; Mack, P.; Gsaller, H.; Kneißl, A.; Mori, G. Chemistry of corrosion products on Zn-Al-Mg alloy-coated steel. Corrosion Science 52 (2010) 3271-3279. DOI: 10.1016/j.corsci.2010.05.044.

[5] Volovitch, P.; Vu, T.N.; Allély, C.; Abdel Aal, A.; Ogle, K. Understanding corrosion via corrosion product characterization: II. Role of alloying elements in improving the corrosion resistance of Zn-Al-Mg coatings on steel. Corrosion Science 53 (2011) 2437-2445. DOI: 10.1016/j.corsci.2011.03.016.

[6] Prosek, T.; Persson, D.; Stoulil, J.; Thierry, D. Composition of corrosion products formed on Zn-Mg, Zn-Al and Zn-Al-Mg coatings in model atmospheric conditions. Corrosion Science 86 (2014) 231-238. DOI: 10.1016/j.corsci.2014.05.016.

[7] Salgueiro Azevedo, M.; Allély, C.; Ogle, K.; Volovitch, P. Corrosion mechanisms of Zn(Mg,Al) coated steel in accelerated tests and natural exposure: 1. The role of electrolyte composition in the nature of corrosion products and relative corrosion rate. Corrosion Science 90 (2015) 472-481. DOI: 10.1016/j.corsci.2014.05.014.

[8] Salgueiro Azevedo, M.; Allély, C.; Ogle, K.; Volovitch, P. Corrosion mechanisms of Zn(Mg,Al) coated steel: 2. The effect of Mg and Al alloying on the formation and properties of corrosion products in different electrolytes. Corrosion Science 90 (2015) 482-490. DOI: 10.1016/j.corsci.2014.07.042.

[9] LeBozec, N.; Thierry, D.; Rohwerder, M.; Persson, D.; Luckeneder, G.; Luxem, L. Effect of carbon dioxide on the atmospheric corrosion of Zn-Mg-Al coated steel. Corrosion Science 74 (2013) 379-386. DOI: 10.1016/j.corsci.2013.05.011.

[10] Lee, J.-W.; Park, B.R.; Oh, S.-Y.; Yun, D.W.; Hwang, J.K.; Oh, M.-S.; Kim, S.J. Mechanistic study on the cut-edge corrosion behaviors of Zn-Al-Mg alloy coated steel sheets in chloride containing environments. Corrosion Science 160 (2019) 108170. DOI: 10.1016/j.corsci.2019.108170.

[11] Prosek, T.; Nazarov, A.; Le Gac, A.; Thierry, D. Coil-coated Zn-Mg and Zn-Al-Mg: Effect of climatic parameters on the corrosion at cut edges. Progress in Organic Coatings 83 (2015) 26-35. DOI: 10.1016/j.porgcoat.2015.01.023.

[12] Prosek, T.; Larché, N.; Vlot, M.; Goodwin, F.; Thierry, D. Corrosion performance of Zn-Al-Mg coatings in open and confined zones in conditions simulating automotive applications. Materials and Corrosion 61 (2010) 412-420. DOI: 10.1002/maco.200905425.

[13] LeBozec, N.; Thierry, D.; Persson, D.; Riener, C.K.; Luckeneder, G. Influence of microstructure of zinc-aluminium-magnesium alloy coated steel on the corrosion behavior in outdoor marine atmosphere. Surface and Coatings Technology 374 (2019) 897-909. DOI: 10.1016/j.surfcoat.2019.06.052.

[14] Ahmadi, M. Deformation, Cracking and Formability of Zn-Al-Mg Coatings: Methodology, Optimization and Application. PhD thesis, University of Groningen, 2022. DOI: 10.33612/diss.202021172.

[15] Malla, A.D.; Penney, D.J.; Williams, G.; Goodwin, F.E.; Domingos Cardoso, A.P.; Brooks, M.; et al. The effect of deformation-induced cracks on the corrosion behaviour of HDG Zn-Mg-Al coatings. npj Materials Degradation 10 (2026) 81. DOI: 10.1038/s41529-026-00800-0.

[16] He, X.; Zhou, X.; Shang, T.; et al. Influence mechanism of different elements and alloy phases on the corrosion resistance of Zn-Al-Mg coated steel in the atmospheric environment: A review. Corrosion Communications 13 (2024) 49-59. DOI: 10.1016/j.corcom.2023.11.001.

[17] Yadav, V.K.; Oh, M.-S. A comprehensive review on microstructural evolution and corrosion behaviour of hot-dip Zn-Al-Mg coatings on Fe-based alloys. Surfaces and Interfaces 94 (2026) 109577. DOI: 10.1016/j.surfin.2026.109577.

[18] De Bruycker, E.; Zermout, Z.; De Cooman, B.C. Zn-Al-Mg coatings: thermodynamic analysis and microstructure related properties. Materials Science Forum 539-543 (2007) 1276-1281. DOI: 10.4028/www.scientific.net/MSF.539-543.1276.

[19] Commenda, C.; Pühringer, J. Microstructural characterization and quantification of Zn-Al-Mg surface coatings. Materials Characterization 61 (2010) 943-951. DOI: 10.1016/j.matchar.2010.06.008.

[20] Su Dinh, N.; et al. Materials Transactions 52(7) (2011) 1383-1387. Citation reproduced from the supplied slide; bibliographic details could not be independently verified and should be checked before external publication.