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San Francisco

New Zinc-Aluminum-Magnesium (ZM) Metallic Coating for Guardrails

By: Rich Clausius – East Chicago R&D
Michael Gremling – CRM Group
Acknowledgements

ArcelorMittal/CRM Group

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- Claudia Cofano – guardrail design

ArcelorMittal Europe

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- Laurence Dosdat – corrosion expert
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• Hot Dipped Coating Comparison
• Unique Properties
• Corrosion Mechanisms
• Corrosion Performance
• Manufacturing
• Environmentally Friendly
• Performance
• Certification & Awards
• Specifications
• Guardrail Pilot & Evaluation Sites
• Light Poles
• Conclusions
• Questions
What is Magnelis®

Product Description:

• Hot dip Zinc metallic coating with 3.5% Aluminium, & 3% Magnesium

• With improved corrosion performance (sacrificial & barrier) vs. pure zinc (sacrificial only)

• Coating designation is “ZM”

Has a natural dark grey, spangle-free smooth aesthetic surface
How are ZnAlMg Coatings Produced

Continuous Hot Dipped Metallic Coating Process

Key Benefits:
- Continuous automated process
- Online control, uniform coating
- Metallic coating layer of Zn, Al, Mg alloys
- Coating Weight expressed in g/m² (combined both sides)
Hot Dip Metallic Coatings Comparison
ZM vs. GI (Galvanize)

Hot dip metallic coatings morphology (not to scale or equivalent coating thickness)

**Continuous Galvanize**

**Batch Galvanize**

Zn + Fe

ZnAlMg

Ternaire Zn/Al/Mg

Primary zinc dendrite

ZM (Magnetis®)

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Why do we Like It

Unique Properties Magnelis® (ZM) vs. Hot Dip Galvanize (GI)

- Superior corrosion protection (sacrificial & barrier) even in aggressive environments (chloride, ammonia, alkaline, soils, wet concrete)
- Less coating mass required (2 to 3 times) while achieving equivalent/better corrosion performance than GI
- Environmentally friendly (less Zinc runoff & usage).
- Improved cut-edge protection/self healing
- Low coefficient of friction & powdering results in excellent roll forming, bending, punching, & less Zinc tool buildup
- Similar weldability to GI
- Alternative to heavy coating post dip/batch Galvanize and other metals

ZM performance better or equivalent to GI
Corrosion Mechanisms

Improved Corrosion Resistance: **Barrier Oxides**

When the metallic coating (M) corrodes, the corrosion resistance is closely linked to the inhibiting (barrier) properties of corrosion products that precipitate both on steel and coating surfaces.

The more compact and stable the corrosion product layer is, the greater the limiting effect on oxygen reduction resulting in a slower corrosion rate.

For ZM coatings, alloying elements (Al & Mg) contribute to the precipitation of compact and stable corrosion products which strongly inhibits oxygen flow.

3% Mg in the coating insures a stable barrier effect*

* study at Tsukuba University /Japan- March 2010
ZM & GI Corrosion Mechanisms

Corrosion products formed during accelerated corrosion testing

<table>
<thead>
<tr>
<th>Coating</th>
<th>Main corrosion products</th>
<th>Structure</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>GI coating</td>
<td>Zinc oxide (ZnO)</td>
<td>ZnO</td>
<td>Porous corrosion products</td>
</tr>
<tr>
<td>(10µm)</td>
<td>Simonkolleite (ZHC) and AlMg basic salt (LDH)</td>
<td>ZHC / AlMg LDH</td>
<td>Low inhibition</td>
</tr>
<tr>
<td>ZM coating</td>
<td>Simonkolleite (ZHC) and AlMg basic salt (LDH)</td>
<td>ZHC / AlMg LDH</td>
<td>Compact corrosion products</td>
</tr>
<tr>
<td>(10µm)</td>
<td>ZnAl3.5Mg3 coating</td>
<td></td>
<td>High inhibition</td>
</tr>
</tbody>
</table>

- **ZM product with 3.5% Al & 3% Mg is an ideal coating composition** which results in compact corrosion products and exceptional corrosion performance
Corrosion Performance – Self Healing

Cut edge protection

Self Healing Mechanism

- The exposed cut end of substrate is oxidised
- Subjected to rain and condensation
- The zinc-based film containing magnesium on the coating layer migrates over the cut end.
- Disappearing of red rust and increasing of white rust

- Initial exposure period (up to several weeks)
- Intermediate exposure period (beyond several weeks)
- Long exposure period (after more than a year)

White rust
Red rust
Coating layer
Corrosion Performance – Self Healing

Cut edge protection

Self-healing cut edge affect

6 months
30-40% red rust - 60% white rust

16 months
10% red rust - 70% white rust

Outdoor exposure over different time periods of Magnelis® ZM250 with 2 mm thickness in Brest (France)
Marine category C5-M (the most severe)
Institut Français de la Corrosion
Corrosion Performance

Corrosion Resistance: Salt Spray Test

ZM250 (20µ) compared with Z275 (G90) pre galvanized (20µ)

ZM250 (20µ) compared with Z1170 (G380) post/batch galvanized (85µ)

Salt Spray test 2000 hours
Post-galvanised 85 µm coating
Magnetelis® ZM250/20 µm coating

ZM (Magnelis®) outperforms standard continuous and batch galvanized (GI) materials
**Corrosion Performance**

**Corrosion Resistance: Marine/Chloride Environment**

Test Area: Brest, C5M environment (marine, 2 meters from the sea)

Similar test done in Daytona Beach (C4/C5 environment) with even better results

In Marine/Chloride environments Galvanized (GI) steel corrodes 3 times faster than Magnelis® (ZM)
Corrosion Performance

GI (Z) & ZM Mass Loss after 2 & 3 Years – Outdoor Sites:

- Magnelis® (ZM) appears to be the best coating in all environments - mass loss ~2-3 times less than GI
- With chlorides - marine site Brest, France (BR) or without chlorides - rural Maizières, France (MZ) or urban East Chicago, IN (EC) sites
Corrosion Performance

Mobile Exposure on a Truck (in Europe):

- On flat bare panels, no red rust on ZM after 3 years vs. GI red rust at the same coating thickness.
- ZM much better than GI

<table>
<thead>
<tr>
<th>Flat test panels</th>
<th>1 year</th>
<th>2 years</th>
<th>3 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZM 10um (ZM120)</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>GI 10um (Z140, G45)</td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
</tbody>
</table>

Truck driven more than 150,000 km/year, (93,000 mi/yr) in various environments (road salts,...)

28/11/2016
Corrosion Performance

GI (Z) & ZM Cut Edge /Hole Corrosion after 5 years exposure - seashore:

- Sample evaluation at Brest (France) - Seashore
- GI (Z): Self healing observed after 1 year, but protection only lasted 1 year
- ZM: Self healing observed after 1 year, and continues to last at least 5 years
- ZM self healing duration increased by a factor of 4 compared to GI
Manufacturing

Formability: *Excellent workability*

Low friction coefficient and low powdering behavior results in excellent drawing, rolling forming, bending & punching with less tool buildup.

Roll Forming
Welding

Corrosion resistance in Salt Spray test:

<table>
<thead>
<tr>
<th>1 day</th>
<th>8 days</th>
<th>17 days</th>
<th>29 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>24h SST = 1 day</td>
<td>192h SST = 8 days</td>
<td>408h SST = 17 days</td>
<td>696h SST = 29 days</td>
</tr>
<tr>
<td>31/05/2011</td>
<td>7/06/2011</td>
<td>16/06/2011</td>
<td>28/06/2011</td>
</tr>
</tbody>
</table>

Samples description
- ZM with 85% Zn -15% Al weld post coating
- ZM with Al - Al weld post coating
- ZM without weld post coating
- GI without weld post coating
- GI with Al - Al weld post coating

Samples were salt spray tested until they exhibited 5% Red Rust

- Magnelis® ZM120 (10µ) HFI welded tubes are far more corrosion resistant than GI Z275 [G90] (20µ) HFI welded tubes due to Self Healing effect
Environmentally Friendly

Zinc runoff in soils

The application of Magnelis® ensures the preservation of natural resources since it uses less zinc than pure zinc coatings. Magnelis® reduces considerably the zinc runoff in soils.
Durability

Sand abrasion

• Coating hardness has a direct impact on the abrasive wear resistance of the coating

<table>
<thead>
<tr>
<th>Material</th>
<th>Hardness Index (HV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Galvanize</td>
<td>64</td>
</tr>
<tr>
<td>Batch Galvanize</td>
<td>70</td>
</tr>
<tr>
<td>Galvalume® (Aluzinc)</td>
<td>129</td>
</tr>
<tr>
<td>Magnelis®</td>
<td>141</td>
</tr>
</tbody>
</table>

• Magnelis® hardness is much higher (harder) than standard zinc coatings (GI & AZ)

• To date, desert field exposure in Dubai, in collaboration with the French Corrosion Institute, has shown ZM to have 3 times less abrasion/corrosion loss vs. batch galvanize
# Performance Comparison

## HDG (GI) vs. Magnelis® (ZM)

<table>
<thead>
<tr>
<th>Product Features</th>
<th>HDG GI</th>
<th>ZM</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anti-Corrosion Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In a chloride environment (marine site, roadside)</td>
<td>Reference</td>
<td>+++</td>
</tr>
<tr>
<td>In an ammonia environment (barn, farm, greenhouse)</td>
<td>Reference</td>
<td>++</td>
</tr>
<tr>
<td>In an SO(_2) environment (acid/industrial)</td>
<td>Reference</td>
<td>+</td>
</tr>
<tr>
<td>Temporary protection (transport, storage)</td>
<td>Reference</td>
<td>+++</td>
</tr>
<tr>
<td>Edge protection (heavy gauge, perforated sheet)</td>
<td>Reference</td>
<td>+++</td>
</tr>
<tr>
<td>Corrosion of a deformed part (bent or stamped)</td>
<td>Reference</td>
<td>++</td>
</tr>
<tr>
<td><strong>Forming Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bending &amp; roll forming</td>
<td>Reference</td>
<td>+</td>
</tr>
<tr>
<td>Drawing</td>
<td>Reference</td>
<td>+</td>
</tr>
<tr>
<td><strong>Assembling Properties</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spot welding (equivalent thickness)</td>
<td>Reference</td>
<td>=</td>
</tr>
<tr>
<td><strong>Aspect</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual Appearance</td>
<td>Reference</td>
<td>=</td>
</tr>
</tbody>
</table>

= Equivalent  + Superior  − Inferior

ZM performance better or equivalent to HDG (GI)
Certifications

Corrosion Performance:

**CSTB**
(France)

**DIBT**
(Germany)

**SP**
(Sweden)

Magnelis® ZM120 equivalent to Z275
Magnelis® ZM310 in severe environments

Magnelis® ZM120 is KII
Magnelis® ZM310 is KIII

Magnelis® ZM310 is C5

Magnelis® is the first metallic coating C5 certified (certified for 20 years in the most aggressive environments)
Awards

In March 2014, ArcelorMittal received the “Intertraffic Innovation Award 2014” in the Infrastructure Category for the development and use of “Magnelis® Zinc-Magnesium-Aluminum coating with High Strength Low Alloy Steel”
Specifications – ZM Coatings

EU EN10346 & US ASTM A1046, Type 2

EN 10346
July 2015

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

Supersedes EN 10346:2009

ISO 77:145.45

Designation: A1046/A1046M – 17

Standard Specification for Steel Sheet, Zinc-Aluminum-Magnesium Alloy-Coated by the Hot-Dip Process

1. Scope
1.1 This specification covers zinc-aluminum-magnesium alloy-coated steel sheet in coils and cut lengths.

1.2 This product is intended for applications requiring corrosion resistance and paintability.

1.3 The product shall be produced in a number of designations (grades and classes) designed to be compatible with differing application requirements.

1.4 Product furnished under this specification shall conform to the applicable requirements of the latest issue of Specification ASTM A653/A653M, unless otherwise provided herein.

1.5 The test of this standard requires sections and specimens which provide exploratory material. These notes and forms, excluding those in tables and figures, shall not be considered as requirements of the standard.

1.6 This specification is applicable to orders in either inch-pound units (as A194) or SI units (as A1046M). Values in inch-pound and SI units are not necessarily equivalent. Within the text, SI units are shown in brackets. Each system shall be used independently of the other.

1.7 Unless the order specifies the “M” designation (SI units), the product shall be furnished in inch-pound units.

1.8 This standard does not purport to address all of the safety concerns, if any, associated with its use; it is the responsibility of the user of the standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

2. Referenced Documents
2.1 ASTM standards:

A653/A653M Test Method for Weight (Mass) of Coating on Iron and Steel Articles with Zinc or Zinc-Alloy Coatings
ASTM/A554/95M Specification for Steel Sheet, Carbon Structural and High Strength Low Alloy, Hot-Rolled and Cold-Rolled, General Requirements for
A575/A575M Specification for General Requirements for Steel Sheet, Galvanized-Coated by the Hot Dip Process
EN ISO 10907 Test Method for Basic Stress-Strain Curves for Metal Sheet Materials

3. Terminology

3.1 Definitions:
See Terminology A653 for definitions of general terminology relating to metallic coated hot-dip products.

4. Classification
4.1 The material is available in several designations as follows:

1.1 Commercial Steel...C Type A. B, and C.
1.2 Deep Drawing Steel...DS.
1.3 Extra Deep Drawing Steel...EDS.
1.4 Forming Steel...15 Type A, B, and C.
1.5 High Strength Low Alloy Steel...HSLA.
1.6 High Strength Low Alloy Steel with Improved Formability...HSLAF.
1.7 Structures Steel...SS.
4.2 Structured steel and high strength low alloy steel are available in several grades based on mechanical properties. Universal Steel Grade 51 [515] is available in four classes based on tensile strength.

4.3 The product is available in several coating weights (mass) with the coating designation in accordance with Table 4.1.

5. Ordering Information

5.1 Zinc-aluminum-magnesium alloy-coated steel sheet in coils and cut lengths is produced to thickness requirements expressed in G60 (155 µm). The thickness includes the coating base metal and the coating.
Guardrail Pilot Site – Izola, Slovenia

* Note: Pictures of Magnelis® (ZM) guardrail in Izola, Slovenia near the Adriatic Sea
Guardrail Evaluation Site – Spain

* Note: Pictures of Magnelis® (ZM) guardrail
Guardrail Installation

Approved Countries:

✓ Belgium
✓ Chile
✓ Czech Republic
✓ Norway
✓ Spain
✓ Approval for other countries in progress

New Installations:

✓ Czech Republic - Two newly rebuilt sections of the Czech Republic’s D1 motorway from Jihlava to Velký Beranov and from Velká Bíteš to Devět křížů, will be equipped with safety barriers using Magnelis® coating. A total of 23 km of one and two-way traffic barriers will be installed between June and November 2017.
Light Poles – Gent, Belgium

* Note: Pictures of Magnelis® (ZM) light poles in Gent, Belgium
Conclusions

Magnelis® (ZM) offers:

- Superior corrosion protection (sacrificial & barrier) even in aggressive environments with less coating mass
- Less coating mass required (2 to 3 times less) while achieving equivalent/better corrosion performance than GI
- Edges protection thanks to the self healing effect
- Good weldability (similar to GI)
- Excellent formability and durability
- Environmental friendly coating (less zinc runoff)
- The first C5 (severe environment) certified metallic coating
- An alternative solution to batch galvanized products and other metals
Questions?

Much more than steel ...

From steel to safety