ArcelorMittal

Magnelis®
technical guide

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Magnelis® technical guide

Metallic coated steel in our daily life

Metallic coated steel is an integral part of our daily life. It is used to protect and shelter us, package and transport goods, and meet our demands for a solid, durable and aesthetically pleasing material.

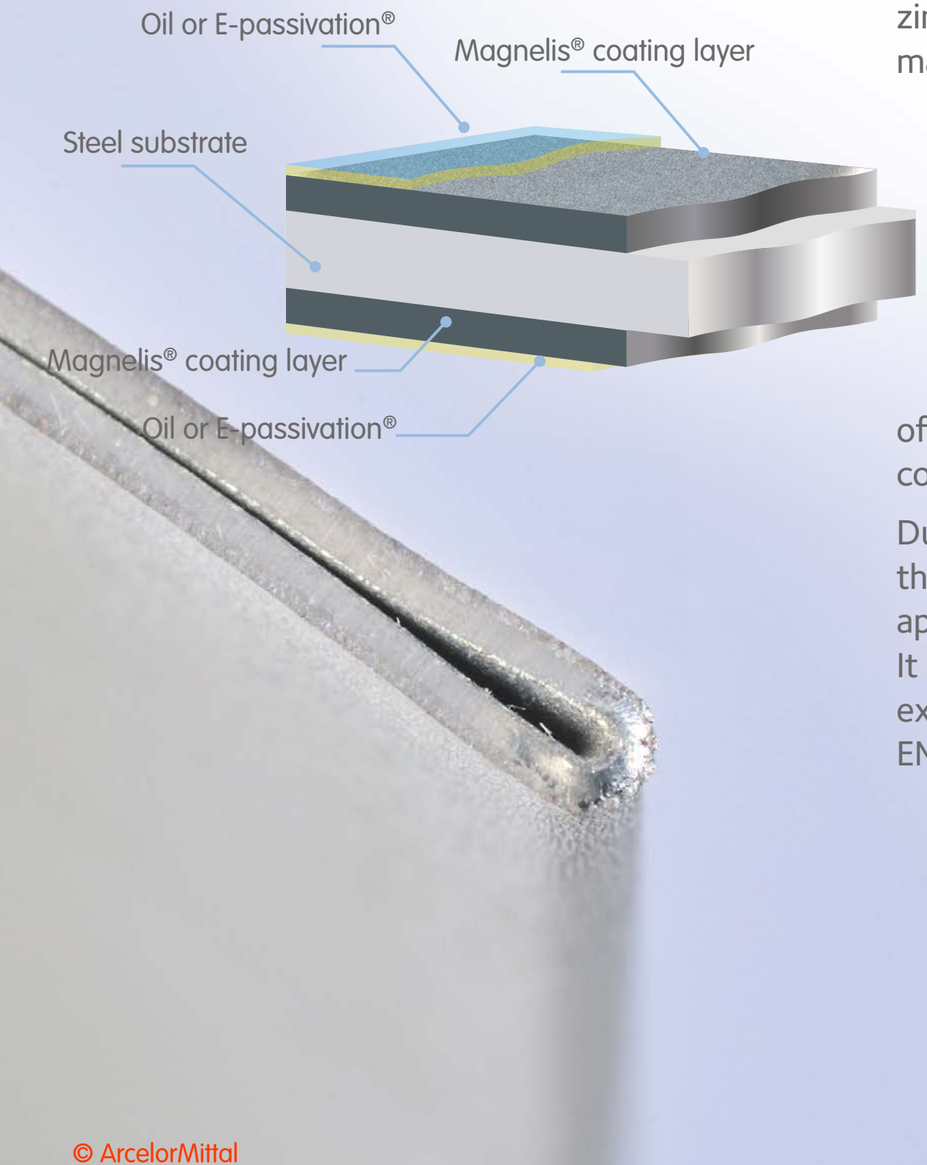
Metallic coated steel has experienced remarkable growth and continues to find applications in an increasingly varied range of fields. This is due to its outstanding economic, technological, and environmental advantages. Some of the key markets include:

- Building and construction: Metallic coated steel has been used to create profiled parts for roofing and cladding, and as cold formed sections for many years. But it is also used for applications such as doors, stairs, and ceilings.
- Road infrastructure: Safety barriers, lighting poles, and acoustic walls all benefit from the long-term corrosion protection of metallic coated steel.
- Solar: A key application is in the structures which support solar installations.
- General industry: Increasingly metallic coated steels are used to create applications such as furniture, air conditioning, tanks, thermal shields, and cable trays amongst others.
- Domestic appliances: This sector is a big user of metallic coated steel. Today's trends see domestic appliances built entirely from metallic coated steel. This includes white goods (refrigerators, washing machines, ovens) and brown goods (electronics, video, hi-fi).

Magnelis®, the metallic coated steel from ArcelorMittal, offers a breakthrough in corrosion protection and a cost-effective solution for all of these sectors. Magnelis® can be utilised with a wide range of manufacturing techniques, resulting in outstanding economic, technological, and environmental advantages for the end product.

ArcelorMittal can provide the necessary technical assistance to help customers select the best-performing and most economically advantageous Magnelis® steel for their application. Our goal is to create long-term successful partnerships with our customers.

What is Magnelis®?



Magnelis® is part of ArcelorMittal's family of metallic coated steel products and is compound of a steel substrate coated both sides. Magnelis® has a unique patented chemical composition including zinc with the addition of 3.5% aluminium and 3% magnesium.

Magnelis® offers a breakthrough in corrosion protection on the surface, and on deformed zones, edges, and perforations thanks to its self-healing effect. Due to its specific composition, Magnelis® develops dense and ordered corrosion protection across its entire surface, including cut edges, in all types of natural environments. This is not the case for coatings with less aluminium and magnesium.

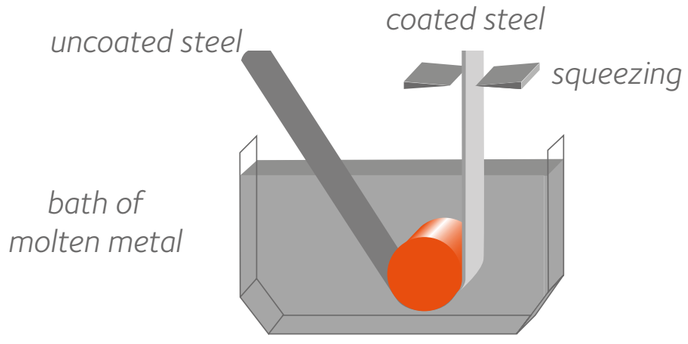
Due to the normal solidification of the coating, the surface of Magnelis® has a uniform metallic appearance and may appear slightly matt to bright. It may also show variations in appearance and exhibit a tendency to darkening over time (see EN 10346: 2015).

Magnelis® has a density of 6.2 g/cm³.
It is available with environmental friendly E-passivation® or Easyfilm® or oiled on request.

The coating weight of Magnelis® is indicated by the number which follows the initials ZM in the product name. Magnelis® meets (and in some cases exceeds) the requirements of the EN 10346: 2015 norm.

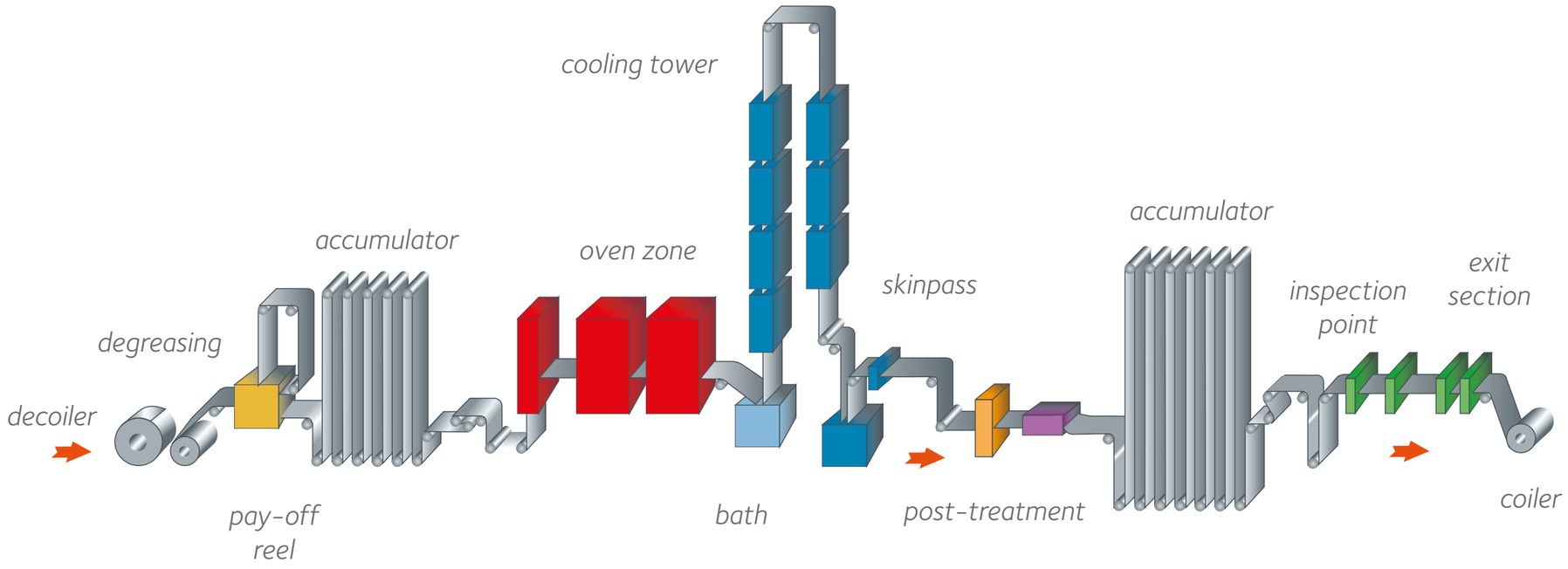
Magnelis® production

Manufactured on continuous production lines, Magnelis® is applied continuously to a steel strip passing through a bath of molten metal.



The layout of a continuous galvanising line consists of three main sections: entry, central section (annealing, metallic coating application, surface treatments), and exit.

The main difference for Magnelis® production is the composition of the molten bath. For Magnelis®, the molten bath includes zinc, aluminium and magnesium.



Corrosion resistance

Thanks to its specific aluminium and magnesium content, Magnelis® offers self-healing on cut edges and superior corrosion resistance in chloride and ammonia atmospheres. Manufacturers can choose a thicker coating to enhance corrosion protection in harsh environments. In applications for gentler environments, a thinner coating can be utilised. A thinner coating facilitates processing steps such as welding.

No other metallic coating offers better protection than Magnelis® in environments with high levels of chloride or ammonia.

Temporary corrosion resistance

To provide Magnelis® with the right temporary corrosion protection during handling, transport, and storage, our E-Passivation® surface treatment is applied to Magnelis®.
This layer is an environmentally friendly, chromate-free passivation which is suitable for a temporary corrosion protection.

Magnelis® shows less than 5% white rust after a 72-hour salt spray test. By comparison, galvanised material can show 5% white rust after just 24-hours.

Processing

The zinc-rich composition of the coating ensures that the same conventional processing operations used with standard hot dip galvanised steel can be utilised with Magnelis®.

These operations include: bending, drawing, clinching, profiling, stamping and welding.

The friction coefficient of Magnelis® coated steel is lower than that standard hot dip galvanised steel and remains stable during forming operations. The result is that Magnelis® is easier to process.

Hardness and scratch resistance

The surface hardness of Magnelis® is more than 2 times higher than that of hot dip galvanised steel. This has a direct and positive impact on the abrasive wear resistance and scratch resistance of Magnelis® coated steel.

The wear-resistance of Magnelis® makes it suitable for use in harsh environments such as deserts (where it withstands sand abrasion), agriculture (resists scratches from animals), and high-wear environments.

Temperature resistance

Magnelis® has the same temperature resistance as hot dip galvanised material. In long-term, continuous exposure, the recommended maximum temperature is 200°C.

For short-term usage, the recommended maximum service temperature is around 300°C.

Surface conductivity

Using the Loresta method ArcelorMittal has confirmed that the surface of Magnelis® conducts electricity. Magnelis® must be insulated to avoid the load of electrical charges. This is an important consideration in applications such as cable trays, photovoltaic solar structures or electrical cabinets.

Feasibility

Magnelis® is available in a very wide range of dimensions, steel grades, and coating weights.

The density of the Magnelis® coating is 6.2 g/cm^3.

Magnelis® coated steel coils are delivered within the tolerances specified in the most recent European standards with regard to thickness, flatness, and width. Different tolerances on dimensions and flatness can be requested.

The Magnelis® data sheet gives detailed information on mechanical properties, chemical composition, dimensional range, advantages and recommendations for use.

Coating code		ZM70	ZM90	ZM120	ZM175	ZM200	ZM250	ZM310	ZM430
Coating mass (total both sides)	g/m²	70	90	120	175	200	250	310	430
	oz/ft²	0.23	0.30	0.40	0.60	0.65	0.80	1.00	1.40
Coating thickness	(µm/per side)	5	7	10	14	16	20	25	35

Aspect	MA and MB aspect *
Surface treatment	C (E-passivation® CrVI-free), O (oiled) and S (Easyfilm®, CrVI-free)* on request
Thickness	0.40 to 6.00 mm (0.018 to 0.236 inches)
Width	Up to 1680 mm (66 inches)

Steel grades*
DX51D to DX57D+ZM
S220GD to S450GD+ZM (according to EN 10346:2015)
S420GD-HyPer® to S700GD-HyPer®+ZM (Eurocode compliant)
HX260LAD up to HX500LAD+ZM (according to EN 10346:2015)
HX600LAD and HX700LAD+ZM

** For detailed feasibility, please contact us.*

Standards

European standard

Magnelis® is included in the most recent version of the EN 10346:2015 standard.

The European standard EN 10346, related to hot dip galvanised (HDG) products, was extended in July 2015 to include zinc-aluminium-magnesium coatings. Whenever norm compliance is a prerequisite, architects, engineers and construction companies can now propose Magnelis®. Magnelis® is the preferred material for an increasing number of applications, including solar support structures, light steel framing in construction, agricultural applications and road infrastructure.

American standard

Magnelis® is included in the new version of ASTM A1046-17. The standard specifies four types of ZnAlMg coatings. Magnelis® is classified as a Type 2 coating.

Certifications

Technical approvals for construction

Germany: DIBt certification

Magnelis® ZM120, ZM250, ZM310 and ZM430 can be positioned as best-in-class for durability vs other ZM coatings according to DIN 55634-1-2017.

Sweden: RISE certification

Technical approval no. SC0559-13

Magnelis® is the first metallic coated product that is certified for use in a C5 environment.

France: CSTB certification

Magnelis® has been recognised by CSTB as a superior coating after a technical study (Evaluation Technique de Produits et Matériaux).

Russia: Gost

Gost conclusions:

- Low carbon steels with Magnelis® coating have high protective properties and are recommended for the manufacture of bearing structures of curtain wall systems.
- The service life of Magnelis® ZM310 under exposure to moderate aggressive environments (with increased sulfur gas and chlorides) is 25 years.

UK: SCI performance review

The Steel Corrosion Institute, independent expert for the steel construction sector in UK, concluded from its performance review that Magnelis® ZM120 provides corrosion protection which is not less than the corrosion protection provided by Z275 coating and is well suitable for the same applications as the Z275 coating when specified in UK and Irish construction.

Technical approvals for crash barriers

Magnelis® solutions have been certified by bodies which oversee the crash barrier product regulations. Certifications have been granted in Austria, Belgium, the Czech Republic, Norway and Spain.

Certification is ongoing in other countries.

Environment and food

Food Contact

Magnelis® is suitable for food contact applications in accordance with European regulation EC 1935/2004.

RoHS

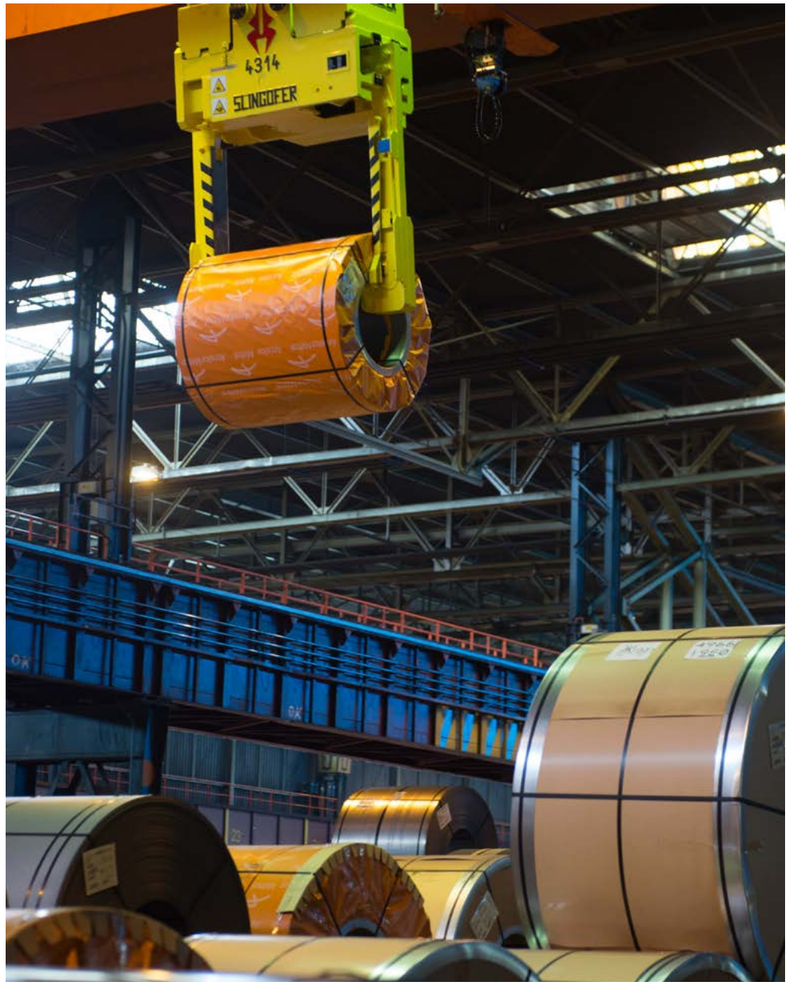
Magnelis® complies with the European directives covering the Restriction of Hazardous Substances (RoHS).

Recommendations for transport and storage

Protection

The space between two laps of a Magnelis® coil, or between two sheets of Magnelis® are areas where oxidation may develop if storage conditions are poor.

To avoid oxidation, additional protective treatments are available and recommended. These include oiling or E-passivation®, both of which will guarantee temporary protection against corrosion. Depending on the transport and storage conditions, this protection will remain effective for 3 to 6 months.



Recommendations for transport and storage

Some simple but essential precautions should be taken during the transport and storage of Magnelis® metallic-coated coils, sheets, and blanks:

- Store Magnelis® in air-conditioned storage facilities to ensure that no moisture accumulates.
- Do not store Magnelis® near windows, doors, or other openings where it can be subjected to extreme variations in temperature. This can produce condensation which leads to corrosion.
- Protect Magnelis® during transport, or if outdoor storage is unavoidable.
- Avoid storing Magnelis® directly on the floor.

Sustainability

Magnelis® is REACH compliant and infinitely recyclable. Steel is the most recycled material in the world.

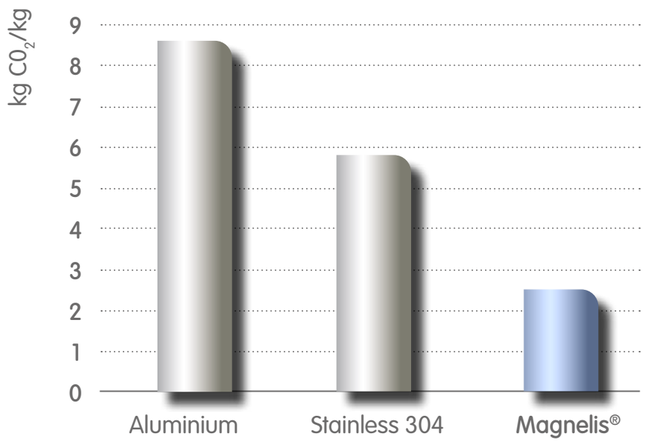
Replacing galvanised steel with Magnelis® reduces the environmental footprint of manufactured products in the following ways:

- Lower use of raw materials and natural resources at galvanising stage: when comparing equivalent performances of Magnelis® and galvanised steel according to their respective EPDs, Magnelis® has 58% less impact on resources consumption and 20% less on energy consumption (ZM120 compared with Z275).
- Lower environmental impact at production level compared to other highly durable materials such as stainless steel or aluminium.
- Reducing zinc runoff during the product's life
- Increasing the lifetime of the finished product

An Environmental Product Declaration (EPD) according to EN15804 is available for Magnelis®. Specific EPDs can be provided on request for other Magnelis® coating weights and steel thicknesses.

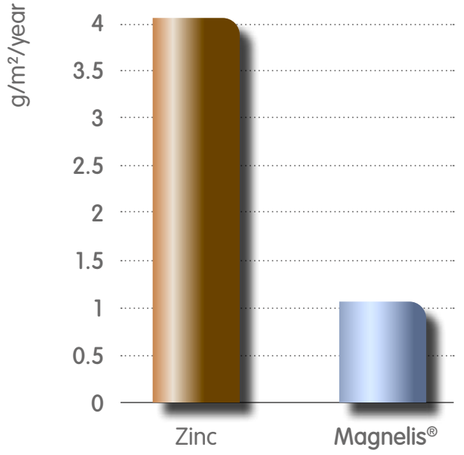
Since 2020, our XCarb® green steel certificates allow customers to report an equivalent reduction in their Scope 3 emissions, in accordance with the Greenhouse Gas Protocol.

Production impact on CO_2 emissions



Sources: ArcelorMittal R&D, European Aluminium Association, World Steel Association, Eurofer

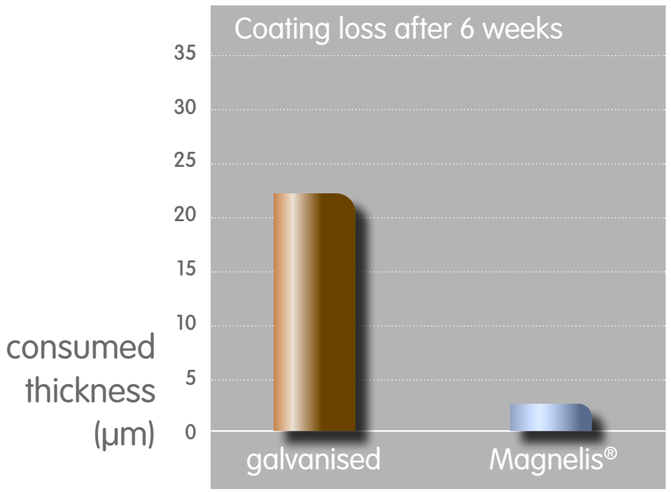
Zinc runoff rate*



** the rate of dissolution of a material from its surface into the soil*
Source: French Corrosion Institute

A breakthrough metallic coating for corrosion protection

With its patented chemical composition, Magnelis® is more resistant against corrosion than conventional hot-dip galvanised steel in all environments.

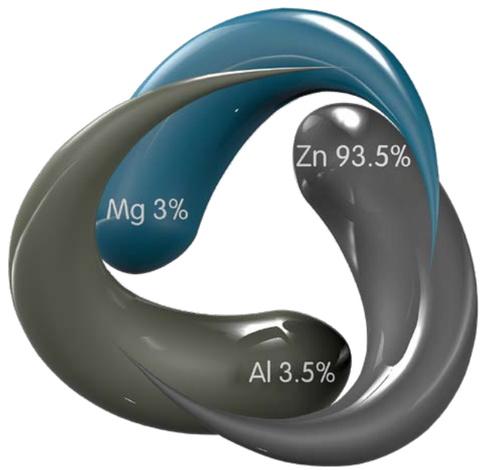


These are results from a 3CT (VDA 621-415) cyclic corrosion test. Source: ArcelorMittal R&D

The addition of 3% Mg and 3.5% Al in the Zn based coating changes the microstructure and the nature of precipitated corrosion products.

A dense barrier and an efficient galvanic protection are created over the full surface of the steel preventing a corrosive attack on the substrate.

The corrosion protection provided by Magnelis® comes from the combination of three mechanisms:

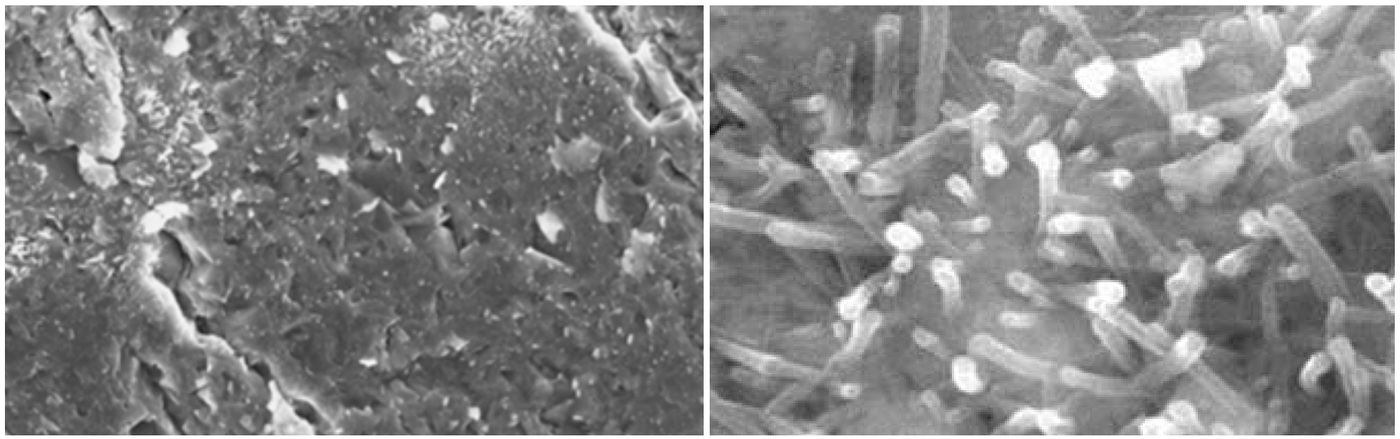


Barrier effect

Shield protection of Magnelis® versus galvanised zinc coating

The outstanding anti-corrosion properties of Magnelis® are due to the formation of highly protective corrosion products which prevent contact between the environment and the steel substrate.

Magnelis® develops dense and ordered corrosion products at the coating surface and at cut edges, in all types of natural environments (marine, industrial, urban, rural). These products protect the steel against corrosion (see image).



Morphology of dense ZnAl LDH (left) formed on Magnelis® and of porous ZnO (right) identified on galvanised coating.

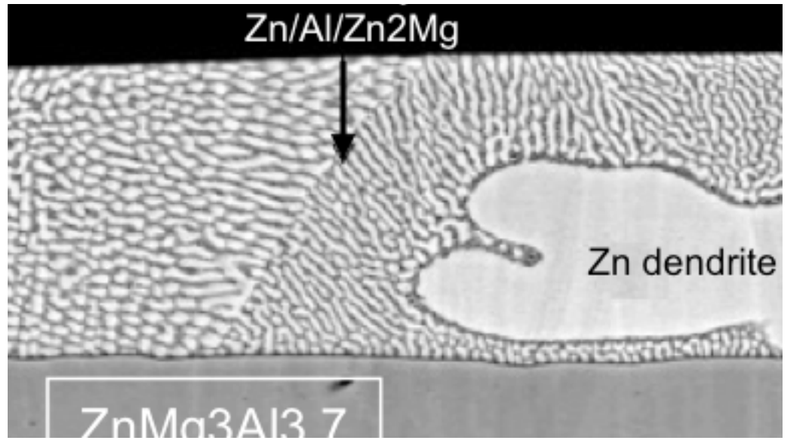
- The very compact ZnAl hydroxycarbonate (ZnAl Layered Double Hydroxyde) formed by Magnelis® has been identified in all corrosive environments and protects the steel against corrosion.
- Other dense and protective oxides have been observed on Magnelis®. They precipitate like basic zinc salts (Zn hydroxychloride and Zn hydroxysulphate). The proportion depends on the chloride and sulphate content of the corrosive atmosphere.
- The ZnO corrosion product, which offers a low level of protection, does not form on Magnelis®. It commonly occurs on other galvanised zinc coatings.

Thanks to its specific composition, Magnelis® can produce these compact products all over its surface. This is not the case for coatings with less Al and Mg content.

Cathodic protection:

Exceptional performance thanks to a specific microstructure

Magnelis® contains Zn dendrites surrounded by a ternary phase of Zn, Al, and intermetallic Zn2Mg (see image). The corrosion potential of Magnelis® is about 40 mV more negative than the corrosion potential of zinc. This is due to a specific ZnMg intermetallic which is more active in the galvanic series than pure Zn, causing preferential corrosion. This explains the reinforced sacrificial power of Magnelis® compared to pure Zn.



Cross section of Magnelis® microstructure

This mechanism is used to protect the steel surface and its uncoated edges (up to a maximum of 2 mm).
For higher thicknesses, Magnelis® protects the steel via its self-healing effect.

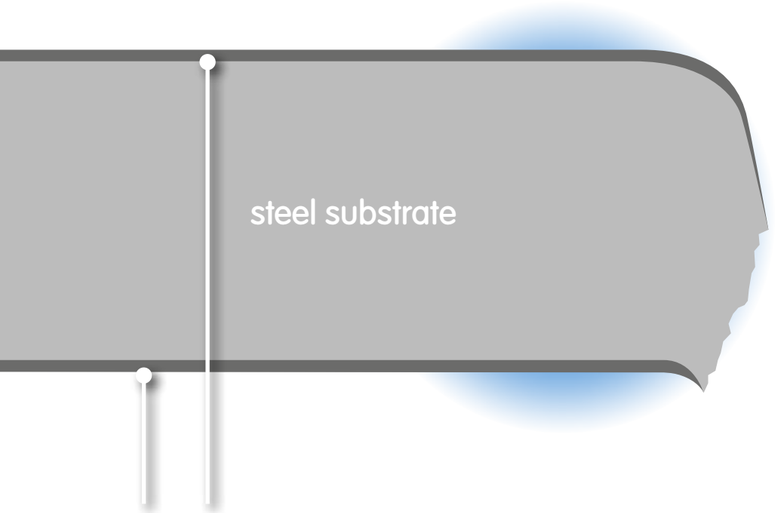
Cathodic protection is a mechanism used to control the corrosion of a metal surface by making it the cathode of an electrochemical cell. A simple method of cathodic protection connects the metal to be protected to a “sacrificial metal”, which corrodes more easily and acts as the anode. The sacrificial metal corrodes instead of the protected metal.

Role of the self-healing effect

If the underlying steel is cut, perforated, or scratched, Magnelis® produces a protective layer which gradually covers the affected area.

The initiation speed and duration of this self-healing protection is influenced by the corrosiveness of the environment.

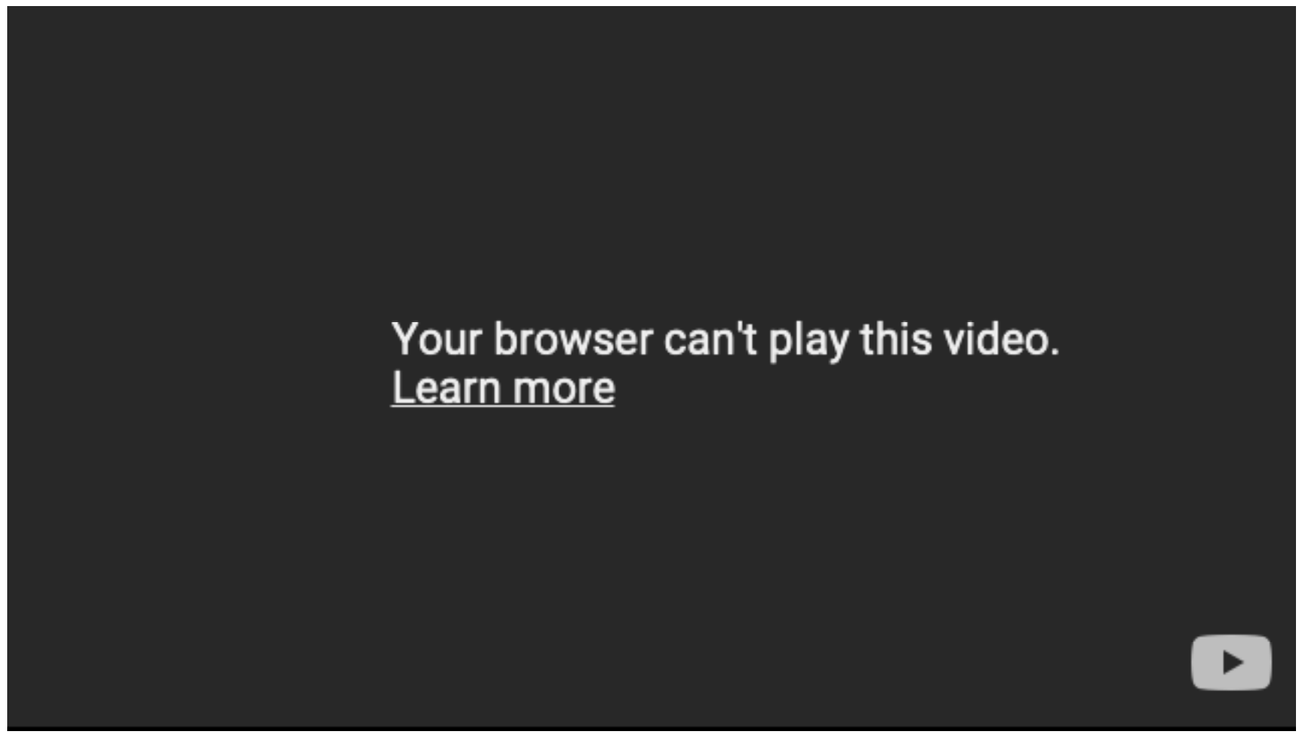
Click or hover the three main stages of self-healing to see the evolving process.



Magnelis® coating

Self-healing is the ability of a coating to produce a compact and stable protective oxide layer on steel surface (covering red rust).

Click to start the video! Problem viewing this video? Visit: Magnelis® self-healing

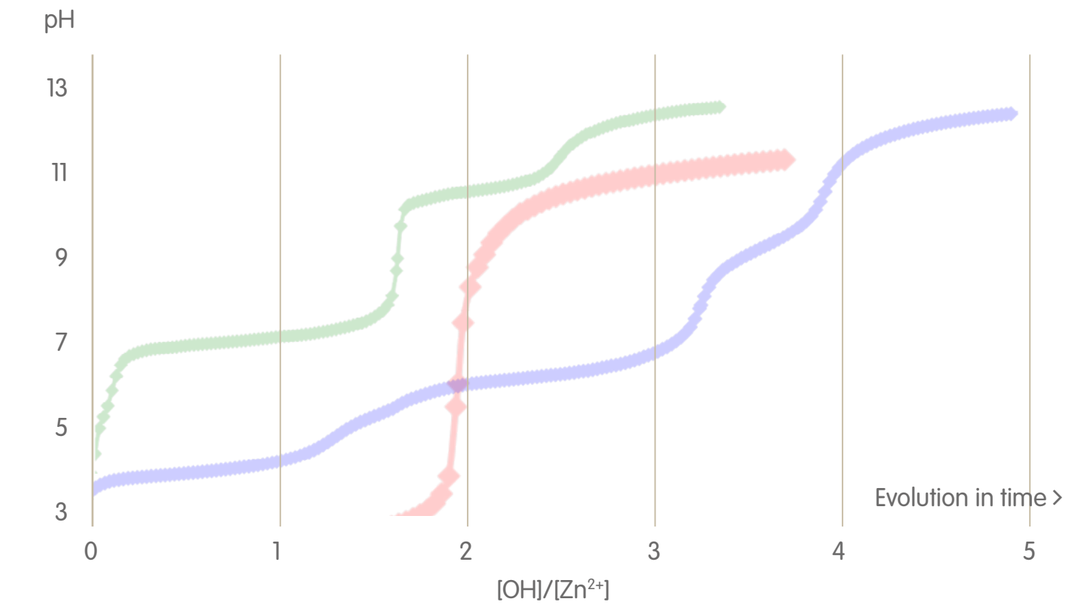


Outstanding protection thanks to controlled content of magnesium and aluminium

Mg and Al play a major role in the corrosion mechanism and therefore on the nature of oxide layers that form during corrosion.

Experimental investigations (electrochemistry, atomic emission spectro-electrochemistry, surface analysis) and thermodynamic modeling have shown that Mg and Al content has a synergistic effect on the corrosion protection offered by Magnelis®.

Influence of Mg and Al on the precipitation of corrosion products



ZHC: Simonkolleite $Zn_5(OH)_8Cl_2.H_2O$
LDH: $Zn_6Al_2(OH)_{16}(Cl)_2;nH_20$
* Then low transformation in ZnO

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Magnelis®

- Magnelis®, with its patented composition, is more resistant against corrosion than galvanised steel
- A dense and compact protective layer is formed on the surface of Magnelis® in every type of environment
- Magnesium and aluminium are key to the success of Magnelis®. This specific alloy composition induces a homogeneous formation of compact protective products on the full surface

Flat surfaces

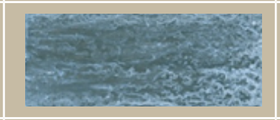
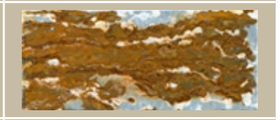
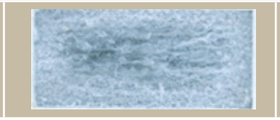
Comparison in salt spray test

Accelerated laboratory tests are a useful way to assess the relative performance of a new solution against reference materials. ArcelorMittal R&D performed numerous and various accelerated tests on Magnelis®.

However, as accelerated tests do not perfectly reflect real life behaviour, many tests were also performed in real outdoor exposure (See the Outdoor Exposure section)

Magnelis® versus pre-galvanised

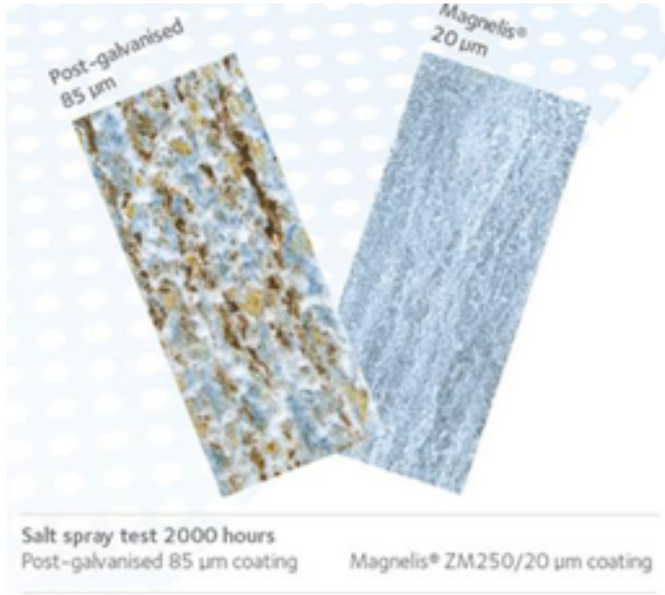
To evaluate the corrosion resistance of Magnelis®, a neutral salt spray test (SST) was conducted in accordance with ASTM B117/NBN ISO 9227 standards to compare it against a continuously galvanised steel. 20 µm thick Magnelis® and galvanised steel were compared. Neither sample was E-passivated.

	Magnelis® 20 microns	galvanised 20 microns
1 cycle		
6 cycles		
52 cycles		removed after 6 weeks

SST comparison of corrosion evolution on Magnelis® and galvanised steel on flat samples (20 micron coatings, without E-passivation®).

Magnelis® versus post-galvanised

An SST was also conducted to compare Magnelis® with batch galvanised material. 20 µm thick Magnelis® and batch galvanised 85 µm were compared for 2000 hours.



Comparison of corrosion resistance on Magnelis® (right) and batch galvanised (left) flat samples after 2000 hours of SST.

During SST, Magnelis® outperformed a galvanised coating of the same thickness and a thicker batch galvanised material.

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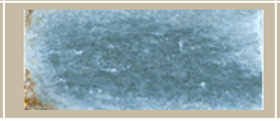
Flat surfaces

Comparison in cyclic corrosion test (3CT)

Magnelis® versus pre-galvanised

Flat samples were also compared in a cyclic corrosion test (3CT) according to VDA 621-415.

	Magnelis® 20 microns	galvanised 20 microns
1 cycle		
6 cycles		
52 cycles		removed after 6 weeks

Corrosion evolution on Magnelis® and galvanised flat samples (20 micron coatings, both non E-passivated) in 3CT.

Magnelis® versus post-galvanised

The same 3CT test was conducted to compare Magnelis® with batch galvanised material. 25 µm thick Magnelis® was compared to 50 µm batch galvanised material.

	20 cycles	29 cycles	39 cycles
Magnelis® 25 µm			
Batch galvanised 50 µm			STOP

Corrosion evolution of Magnelis® (top) and batch galvanised flat samples in 3CT.

The success of this test indicates that Magnelis® can be an alternative to thicker galvanised material and to batch galvanisation. Magnelis® can offer similar corrosion resistance to batch galvanised material.

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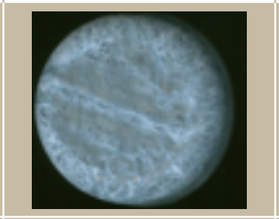
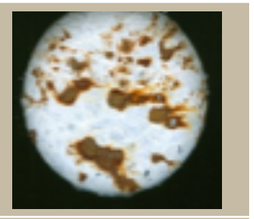
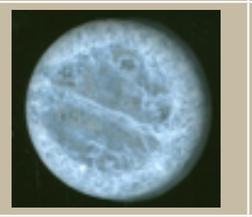
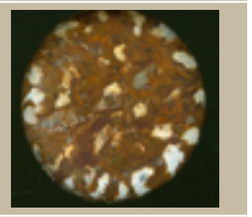
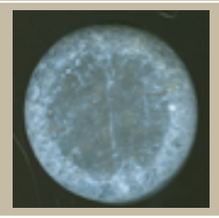
Deformed parts

Magnelis® versus pre-galvanised coatings

After forming, the Magnelis® layer resistance produces its specific corrosion resistance products. The products form a compact and dense protection layer which ensures a more effective corrosion protection, even on deep drawn parts, compared to galvanised material.

Salt spray test

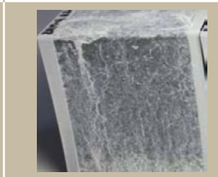
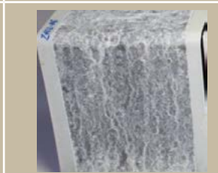
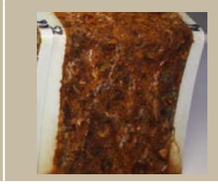
A neutral salt spray test (SST) was conducted on deformed parts in accordance with ASTM B117/ NBN ISO 9227 standards. Magnelis® and galvanised samples, both non E-passivated and with 20 µm thick coatings, were compared.

	Magnelis® 20 microns	Galvanised 20 microns
10 days		
4 weeks		
6 weeks		

Comparison of corrosion evolution on deep drawn cup samples of Magnelis® and galvanised steel (both non E-passivated) in an SST.

Cyclic corrosion test (3CT)

The same corrosion tests were performed on parts formed by bending or by deep drawing to estimate the impact on corrosion resistance. In both tests, Magnelis® clearly outperformed galvanised steel.

	Bending radius	3 cycles	10 cycles
Magnelis® 20 microns	2 mm		
Galvanised 20 microns			
Magnelis® 20 microns	6 mm		
Galvanised 20 microns			

Comparison of corrosion evolution on bent Magnelis® and galvanised samples (20 micron coatings, both non-E-passivated) in 3CT corrosion test.

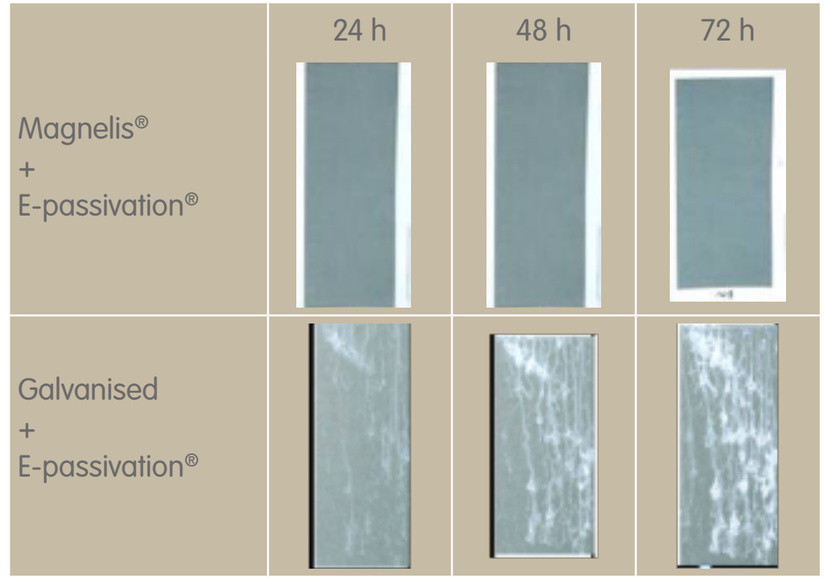
ArcelorMittal

Temporary corrosion protection

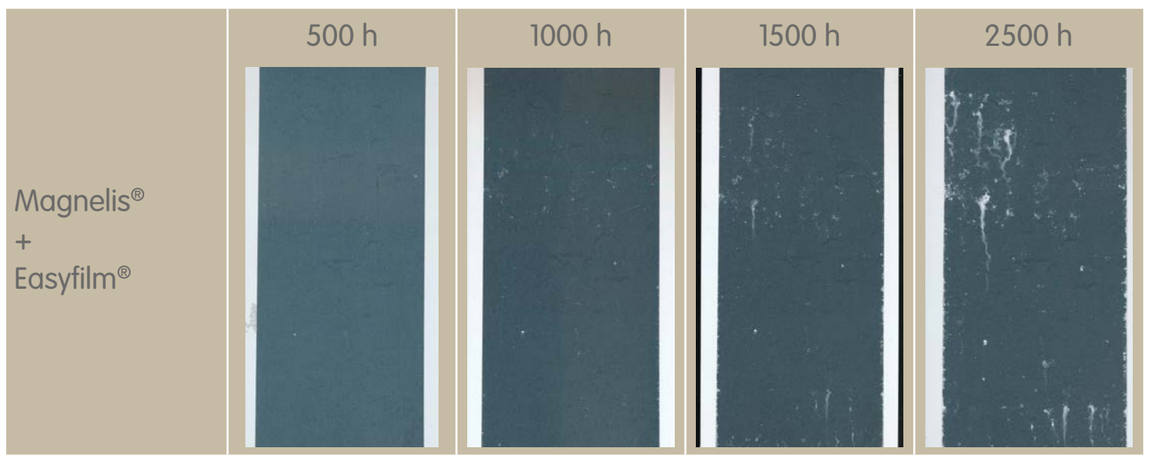
Magnelis® versus pre-galvanised

We provide Magnelis with temporary corrosion protection during handling, transport, and storage. The E-passivation® surface treatment is applied to the product's surface.
This layer is an environmentally friendly, chromate-free passivation which offers temporary corrosion protection.

In good storage and transport conditions, Magnelis® will show less than 5% white rust after 72 hours in a salt spray test. Galvanised material can show 5% white rust after just 24 hours (see image).



White rust % evolution on flat samples of Magnelis® and galvanised material (both passivated) in SST



White rust evolution on a flat sample of Magnelis® + Easyfilm®

Another surface treatment is now available on Magnelis® surface. Easyfilm®, a chromate-free thin organic coating, improves even further the temporary corrosion protection. With Easyfilm, Magnelis® will show less than 5% white rust after minimum 500 hours of salt spray test.

Both with E-passivation® and with Easyfilm®, the temporary corrosion protection is independent of the thickness of the metallic Magnelis® coating layer.

- The superior corrosion protection of Magnelis® compared to galvanised and post-galvanised material has been demonstrated both on flat and deformed parts (bent and deep drawn) in both salt spray and 3CT tests.
- E-passivated Magnelis®, and even more so Easyfilm® on Magnelis® significantly increase the resistance to white rust.

Magnelis®, a breakthrough metallic coating for corrosion protection

Outdoor exposure tests are the most reliable way to assess the anti-corrosion properties of new products. Although outdoor testing takes a long time, it enables us to obtain information about the real behaviour and durability of the product in different conditions (polluted environments, extreme temperatures, wet conditions).

During the development of Magnelis®, outdoor exposure tests were launched in several sites around the world. These tests covered the full range of outdoor environment categories (rural, industrial, marine, tropical, ...).

Magnelis® behaviour in aggressive environments

Tests were conducted to measure the ability of Magnelis® to act as barrier against corrosion in aggressive environments. Material stability is typically assessed by measuring weight loss. The barrier effect of Magnelis® was compared to galvanised zinc coating in more than 10 different sites. These sites cover outdoor environment categories C2 to C5 (according to ISO 12944-2).

Corrosion category for Zn (ISO 12994-2:2017)	Coating design life (years)	
	Magnelis® ZM310	Magnelis® ZM430
C2	> 50	> 50
C3	30 to > 50	40 to > 50
C4	15 to 30	20 to 40
C5	8 to 15	10 to 20

Two main conclusions can be drawn from this extended outdoor exposure testing:

- Magnelis® provides in average three times the protection offered by galvanised steel in all types of environments.
- The durability of Magnelis® is much less sensitive to harsh environments such as those containing chloride (de-icing salts, marine sites...).

Based on extensive outdoor field tests, ArcelorMittal has calculated the coating design life expectations for Magnelis® ZM310 and ZM430 (respectively 25 and 35 microns per side).

The expected coating design life is the average time until 100% of the undamaged coating, exposed only to atmospheric conditions, is consumed on the surface. At that point, the structural integrity of the coated part is no longer assured and major repair is necessary.
These estimates are valid for both outdoor and indoor applications, excluding situations where the coating is in permanent contact with a moisture source, such as soil or concrete.

Magnelis® behaviour on edges

Magnelis® improves steel durability in two ways: through galvanic protection and its self-healing effect.

For information on galvanic protection, see Magnelis® corrosion mechanisms

On cut edges, the steel substrate protection is supported by the self-healing effect of Magnelis®.

To assess the self-healing mechanism, perforated panels of both Magnelis® and a galvanised zinc coating (both 2 mm thick) were exposed to a marine environment in Brest (France) for ten years. During that period, we observed that self-healing appeared on both the galvanised zinc coating and on Magnelis® .

While an oxide film was formed on the edges of the steel on both materials, we noticed that the protection from the galvanised coating was not stable enough to protect the perforated panel during 5 years in case of dense perforation.

However, the better stability of the corrosion products from Magnelis® coating protected all the perforated panels during the 10 years-duration of the exposure test.

Perforated metallic coated samples exposed in Brest by the French Corrosion Institute

Outstanding performance confirmed by outdoor exposure

To test the galvanic protection, thick samples were also exposed outside in different locations. ArcelorMittal researchers observed that a thicker Magnelis® coating could protect thick cut edges.

The kinetics of cut edge protection are influenced by the corrosiveness of the environment. In non-severe environments with very few corrosive compounds, Magnelis® consumption is slow. In these conditions, only a little self-healing effect is visible.

On thicker steel substrates, a higher coating weight is required for optimised edge protection.

For this optimisation, some recommendations are given in the Magnelis® German Technical Approval from DIBt Z-30.11-51. As an example, no edge reprotection is recommended with:

- Magnelis® ZM120 or higher on steel substrate up to 1.5 mm thickness
- Magnelis® ZM250 or higher on up to 3.00 mm thickness
- Magnelis® ZM310 or higher on thicknesses of more than 3.00 mm

See our section on certifications.

Cut edge protection by self-healing has been confirmed by Magnelis® customers on their final products (see example below).

Example of safety barriers:
Follow-up after 1 week, 15 months, and 25 months.
Image shows the cut-edge of a 3 mm thick substrate coated with Magnelis® ZM310 and used for a safety barrier exposed in a rural environment.
These images demonstrate that self-healing depends on the corrosiveness of the environment.

Corrosion behaviour
Concrete

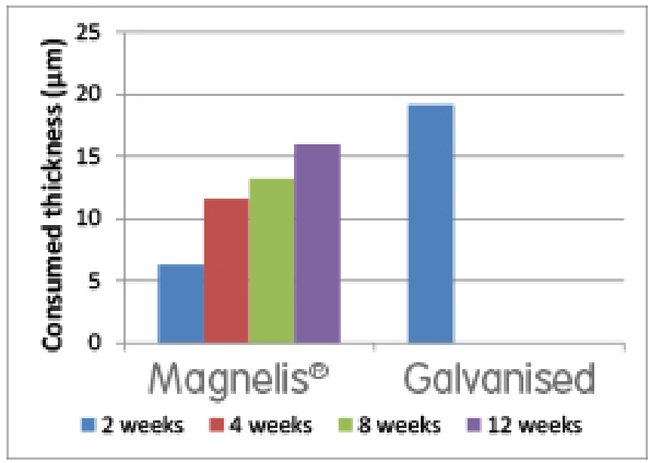
When parts come into contact with concrete, especially in the initial stages when the concrete is still wet, they are exposed to a highly alkaline corrosive environment.

Lab test

In order to simulate this environment, a solution with a pH of approximately 12.5 was used.

The samples of Magnelis® and HDG (hot dip galvanised) material (20 micron coating on each) were immersed in the solution for up to 12 weeks. The level of corrosion (weight loss) on the samples was then measured.

Magnelis® outperformed HDG-Zn samples of comparable thickness.
The consumed thickness of Magnelis® after 12 weeks is lower than that of HDG-Zn after just 2 weeks. No results are available for HDG after 4, 8, or 12 weeks as the coating was completely consumed after 2 weeks.



Tests in concrete

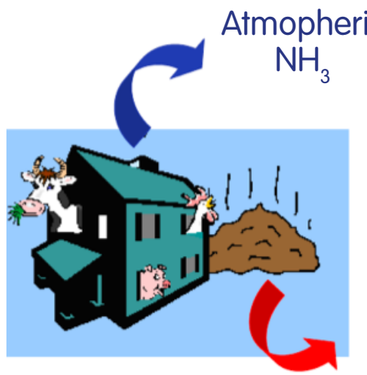
Magnelis® has very good corrosion properties in alkaline environments such as concrete.

In this test, Magnelis® and HDG-Zn were placed in contact with a standard concrete composition. To simulate real conditions, concrete was poured on to metallic coated steel profiles. The whole structure was left to dry for a day, until the concrete hardened. Cross-sectional metallography showed that Magnelis® performed better than HDG-Zn.

ArcelorMittal

Corrosion behaviour
Agriculture

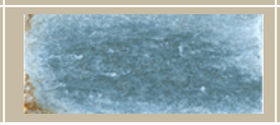
Agricultural environments such as farms or greenhouses are aggressive. They contain a combination of specific pollutants with high pH levels, at high temperatures and high relative humidity.



Lab test

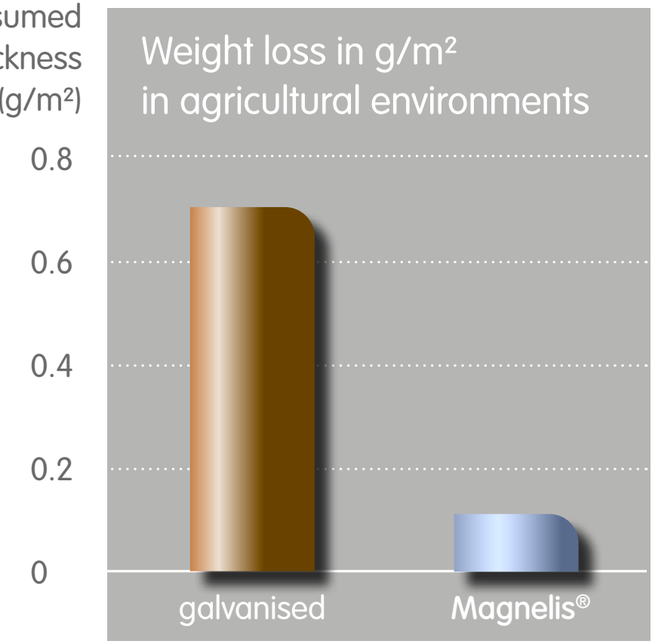
In controlled tests, Magnelis® demonstrated excellent behaviour in the presence of ammonia.

A 3CT test, including phases at 40°C/95% relative humidity and 20°C/70% relative humidity, was performed to simulate hot and humid environments such as greenhouses.

	Magnelis® 20 microns	Galvanised 20 microns
1 cycle		
6 cycles		
52 cycles		removed after 6 weeks

Corrosion evolution of Magnelis® and galvanised flat samples (20 micron coatings, both non E-passivated) in 3CT.

The tests indicate that Magnelis® demonstrates very good corrosion protection in agressive environments which are representative of farms and greenhouses.



Measurement of mass loss:
pH: 11.7, solution with 5% NH_3 ,
T: 20°C, test duration: 24 hours.
Source: ArcelorMittal R&D

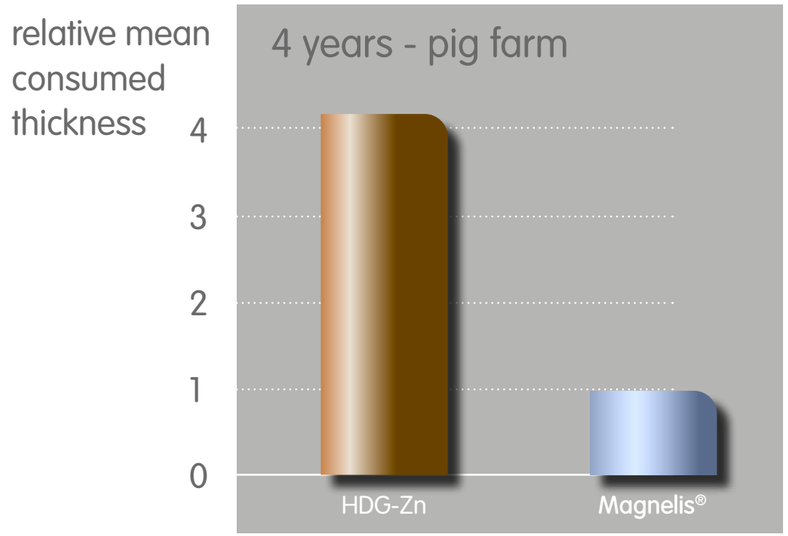
Corrosion behaviour
Agriculture

Tests in agricultural environments

Magnelis® and HDG-Zn samples were also exposed, in a building used to house heaps of cow manure and in a pig farm used to house pregnant pigs.

The samples were left in place for four years and tested after one, two, and four years of exposure. The tests were carried out in collaboration with the French Corrosion Institute.

In both exposure sites, Magnelis® performed much better than HDG-Zn (see graph).



Regardless of the thickness of the coatings, hot-dip galvanised consumes 4 times more of its thickness compared with Magnelis®.

Corrosion behaviour
Soil

Atmospheric corrosion of metals has been studied extensively for years.
Five different atmospheric corrosion categories have been defined as a result of these studies according to ISO 9223.
They range from C1 (non-corrosive) to C5 (highly corrosive).

However, for structures buried in soil, corrosion is local in nature and corrosion categories are difficult to define. As a result the norms regarding soil corrosivity are very limited. Yet there are numerous applications where metallic structures must be buried in soil. It is very important to understand the mechanisms of corrosion in soils and to be able to estimate the soil corrosivity.

An evaluation of this corrosivity can be done by using the German standard DIN 50929-3 : 2018.

Parameters effective on soil corrosion

The corrosion of metallic structures in soils is governed by complex mechanisms. They include chemical and electrochemical reactions, and transport and diffusion processes at the soil/metal interface. There have been many efforts to correlate soil characteristics with the corrosion rates of buried metallic structures. Aeration, water content, pH level, resistivity, and soluble salt content are the main factors affecting soil corrosion.

• Degree of aeration

Oxygen concentration decreases as the depth of soil increases. The role of oxygen in the corrosion process is very important due to its role in the cathodic reaction. The oxygen content of the soil depends on the soil texture and on the soil's ability to diffuse oxygen from the atmosphere. The texture of a soil is defined by its particle size distribution.
The standard particle size classification is shown in Table 1. It is possible to define the texture of a soil depending on the repartition of its particles. A common way to define soil texture is to use a ternary sand-silt-clay diagram (see Figure 1).

Corrosion behaviour
Soil

Field outdoor testing at ArcelorMittal R&D centre (OCAS)

Magnelis® in soils: field test results

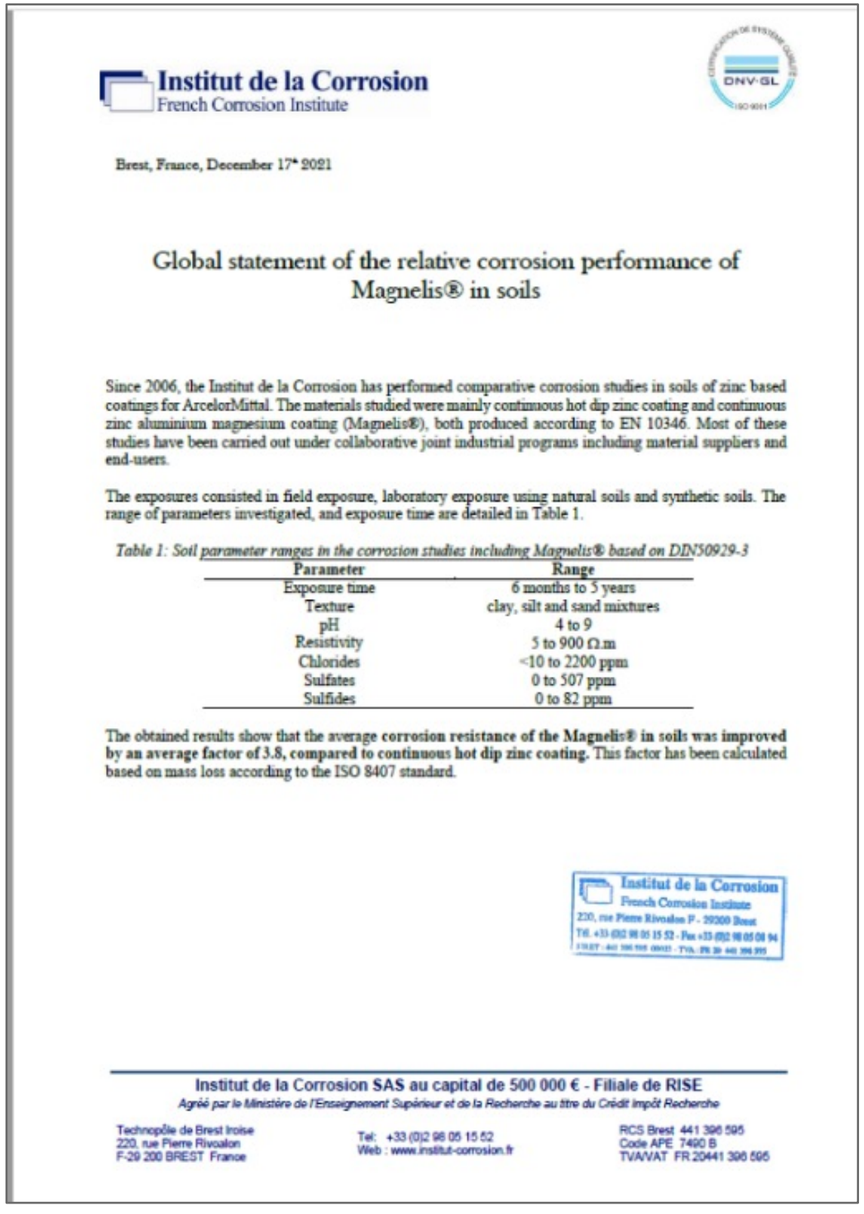
In parallel with lab tests, ArcelorMittal knowledge on Magnelis® behaviour in soils is enhanced by field outdoor testing, and via collaboration with external research centres.

Different types of soils, with different corrosivity levels (evaluated by using the German standard DIN 50929-3 : 2018), are used for these tests.

The results, after years of tests, confirm the improved resistance of Magnelis® compared with batched galvanised steel: the corrosion rate of Magnelis® increases at a lower rate than batch galvanised steel, and with less dispersion of the results.

"Corrosion resistance of Magnelis® in soils was improved by an average factor of 3.8 compared to continuous hot dip zinc coating."

Link to the original document.



Institut de la Corrosion
French Corrosion Institute

Brest, France, December 17th 2021

Global statement of the relative corrosion performance of Magnelis® in soils

Since 2006, the Institut de la Corrosion has performed comparative corrosion studies in soils of zinc based coatings for ArcelorMittal. The materials studied were mainly continuous hot dip zinc coating and continuous zinc aluminium magnesium coating (Magnelis®), both produced according to EN 10346. Most of these studies have been carried out under collaborative joint industrial programs including material suppliers and end-users.

The exposures consisted in field exposure, laboratory exposure using natural soils and synthetic soils. The range of parameters investigated, and exposure time are detailed in Table 1.

Table 1: Soil parameter ranges in the corrosion studies including Magnelis® based on DIN50929-3

Parameter	Range
Exposure time	6 months to 5 years
Texture	clay, silt and sand mixtures
pH	4 to 9
Resistivity	5 to 900 Ω.m
Chlorides	<10 to 2200 ppm
Sulfates	0 to 507 ppm
Sulfides	0 to 82 ppm

The obtained results show that the average **corrosion resistance of the Magnelis® in soils was improved by an average factor of 3.8, compared to continuous hot dip zinc coating.** This factor has been calculated based on mass loss according to the ISO 8407 standard.

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TVA/VAT FR 20441 396 595

Corrosion behaviour
Soil

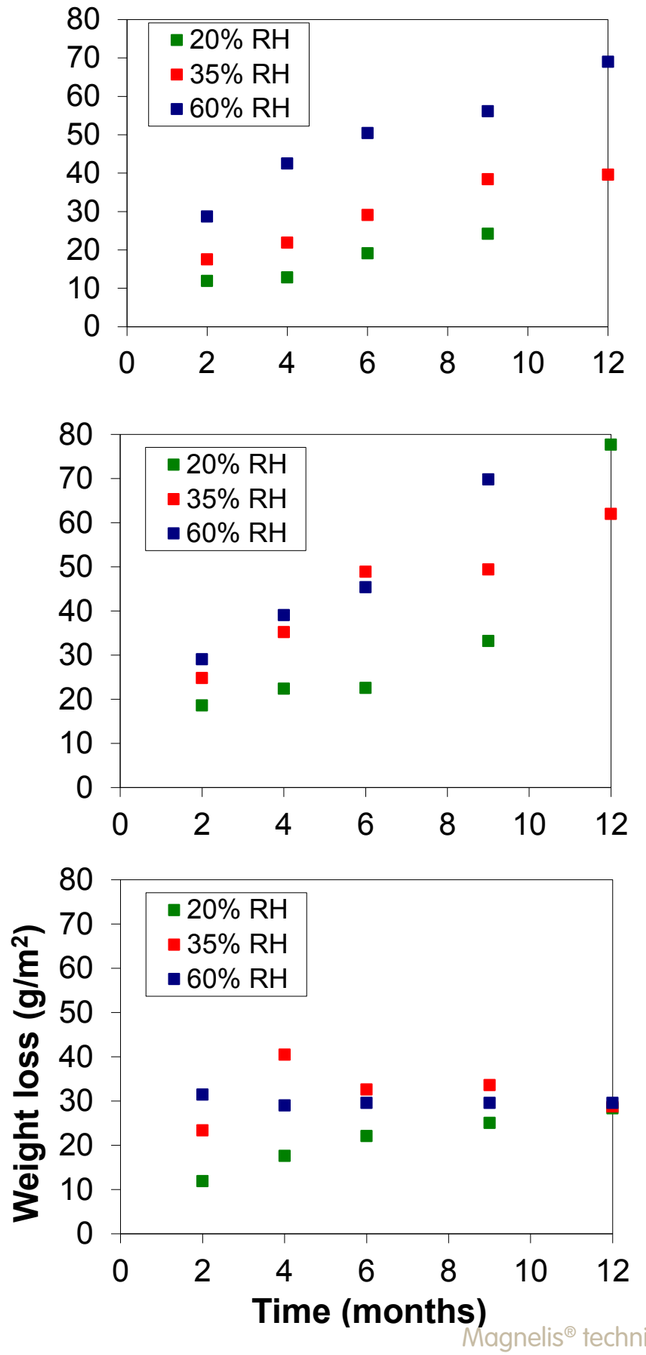
Soil corrosion test methodology

This methodology to measure soil corrosivity was defined in collaboration with the French Corrosion Institute

- Cells (see Figure A) are filled with an artificial soil (Euro-soil 5 according to ISO 11268-1). This consists of a mix of:
  - Standardised sand MI32 (800g) + MI04/09 (5,200g)
  - Clay (1,200g)
  - $CaCO_3$ (40g)
  - Humus (800g)
- The cells were placed vertically in a box.
- The compaction of the soil was controlled over the height of the cell.
- Water level was kept constant through the addition of demineralised water to compensate for evaporation.
- Every fraction (sand, silt, and clay) was separated and the following parameters were

Magnelis® in soils: lab test results

Weight loss measurements taken after one year of laboratory soil corrosion testing, showed that the corrosion rate of Magnelis® tends to be stable with almost no increase in loss between two months and a year. However, the weight loss of the HDG-Zn and batch galvanised samples continuously increased with exposure duration.



Weight loss measurements (top) HDG-Zn, (middle) batch galvanised, and (bottom) Magnelis® samples.Laboratory soil corrosion tests carried out in different levels of relative humidity (20, 35 and 60%)

Corrosion behaviour
Soil

On basis of laboratory and field tests results, Magnelis® ZM430 is the minimal coating thickness recommended for applications in contact with non-aggressive soil. Higher coating weights are required in more aggressive soils.

Its durability is expected to be at least equivalent to batch galvanised coated steel.

This durability can be supported by a guarantee contract granted by ArcelorMittal on a project-by-project basis, following soil physical, chemical and electrical analysis.

Magnelis® ZM430 (~35 µm) is expected to provide durability at least equivalent to 55-70 µm thick batch galvanised coating. This allows manufacturers to reduce the thickness of Magnelis® by around 50% to obtain the equivalent corrosion resistance.

Ultimately, as the durability depends on the aggressiveness of the soil, the boundary conditions on the soil characteristics considered by default for a Magnelis® guarantee are the following:

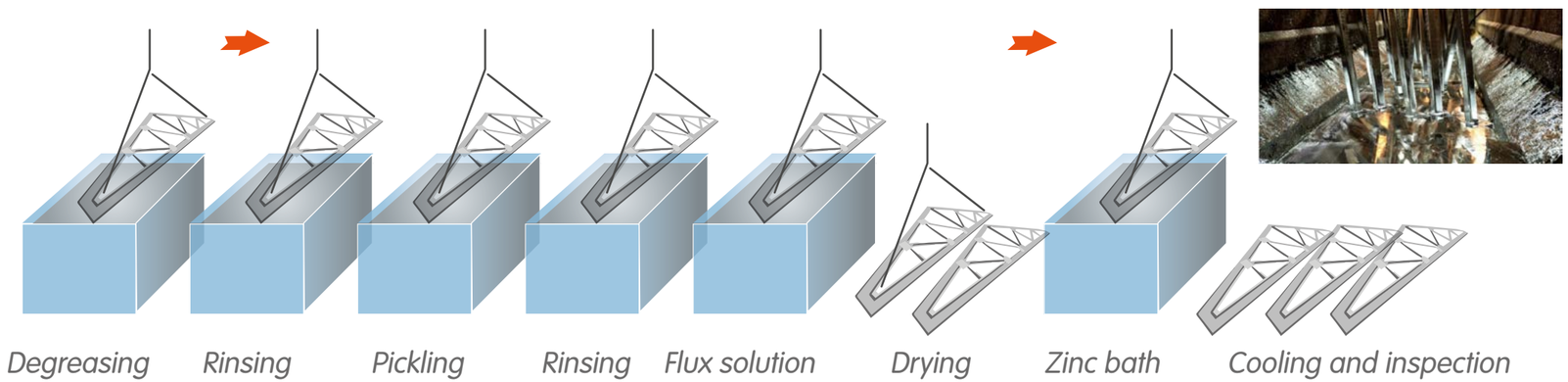
- Gravimetrical content in fine grain < 50 %
- pH between 5.5 and 8.5
- Soil resistivity > 5000 Ω.cm measured on the field at a distance < 6 m (4 points Wenner method)
- Low chloride ion concentration < 150 mg/kg
- Low sulphates concentration < 500 mg/kg
- Low sulphides concentration < 5 mg kg
- No fertiliser, bacterial activity and stray current

Production process

Continuous galvanisation

- Continuous automated process
- 100% online control of surface
- No limit in capacity
- Independent of steel grade and steel thickness

Batch galvanisation



- Discontinuous manual process
- Thermal deformation for thin gauges
- Dependent on steel grade and steel thickness
- OK for welded structures

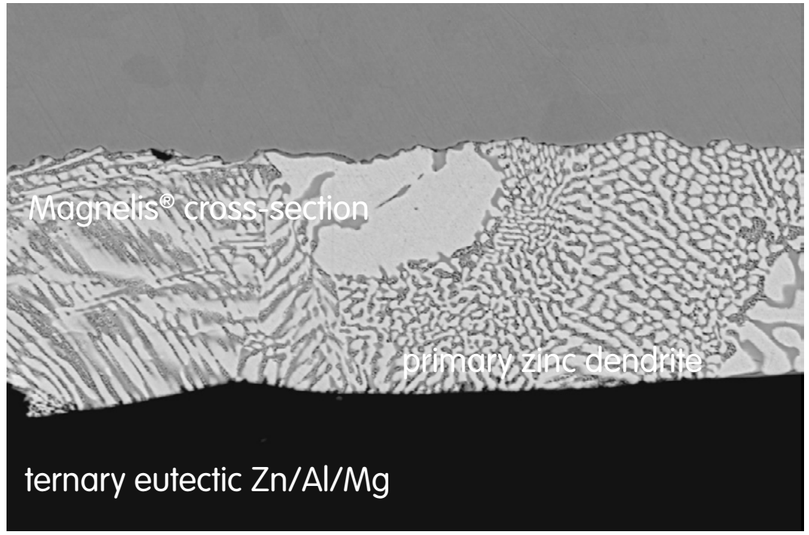
Coating structure

Magnelis®

Like other alloyed coatings, the microstructure of Magnelis® contains phases. The continuous layer contains two main phases:

1. Some primary zinc dendrites
2. These are surrounded by a large quantity of ternary eutectic made of zinc, aluminium, and magnesium.

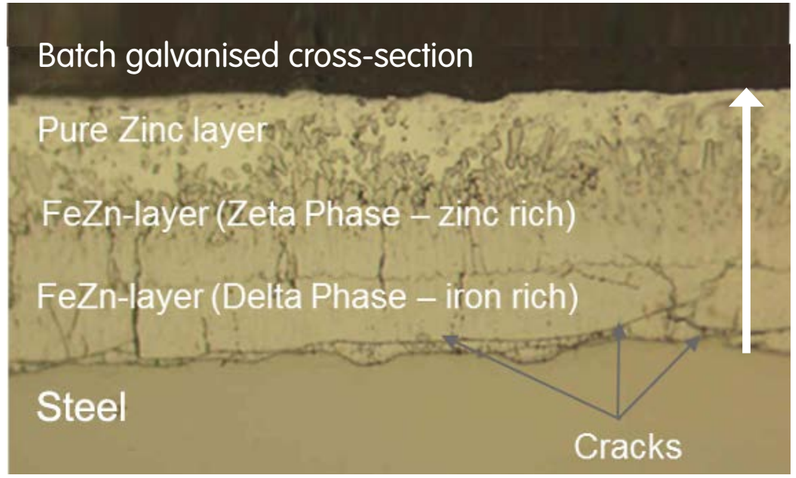
The ternary eutectic matrix produces high-performance anti-corrosion products which take their place homogeneously in the coating layer, ensuring that there is uniform corrosion behaviour.



Batch galvanised

Batch galvanised coatings have a non-homogeneous microstructure made of successive Zn-Fe phase layers. The percentage of iron increases closer to the steel substrate. The upper pure-zinc layer only represents around 30% of the total thickness.

Due to its layered structure, the corrosion behaviour of the coating will depend on the percentage of iron in each layer.



The Fe content of the phases gradually decreases while the Zn content increases

Protection performance

Accelerated tests

Accelerated tests do not perfectly reflect real life behaviour. However, these laboratory tests are a useful way to assess the relative performance of different materials.

A salt spray test (based on the ISO 9227 standard) was conducted to compare a 20 microns thick Magnelis® coating with batch galvanised material with an 83 microns coating.

The following images show the steels after 12 weeks (2016 hours) of testing.

Batch galvanised 83 µm
after 12 weeks

Magnelis® 20 µm
after 12 weeks

Protection performance

Outdoor exposure

The importance of performing field tests to assess coating protection performance has long been recognised. That's why ArcelorMittal Global R&D has performed field tests since Magnelis® was first developed. The tests include comparative testing of post-galvanised material.

Long-duration exposure tests are conducted in outdoor locations to compare the performance of Magnelis® and post-galvanised material. This testing is organised in different locations around the world to obtain a better understanding of the relative behaviour of Magnelis®.

The results confirm the higher resistance of Magnelis® coating to corrosion, regardless of the test environment.

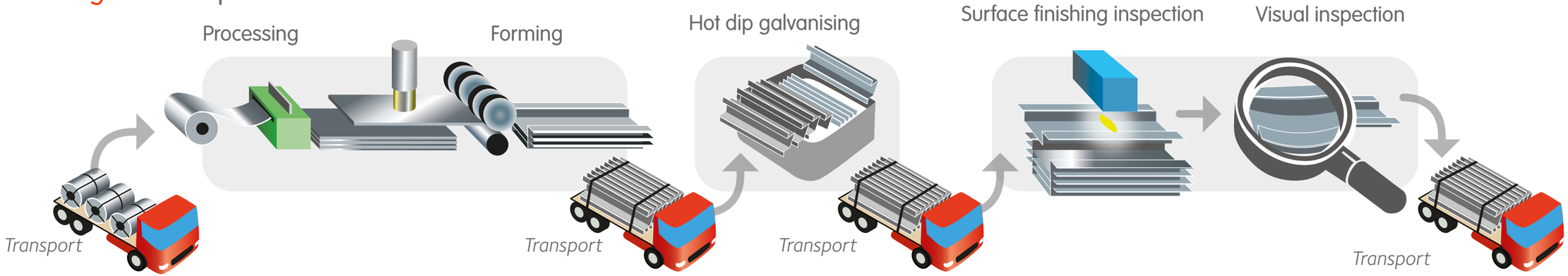
The improvement ratio ranges from a minimum close to 3, and extends to 7 in some marine environments.

The test results show also that Magnelis® exhibits very stable behaviour. Coating consumption rates are relatively low in all environments.

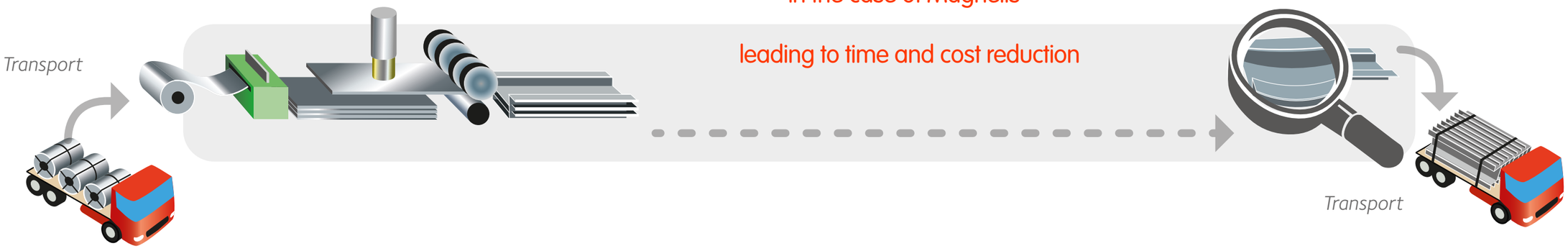
Transport and handling

Magnelis® allows substantial savings in lead time and costs.

Post-galvanised process



Magnelis® process



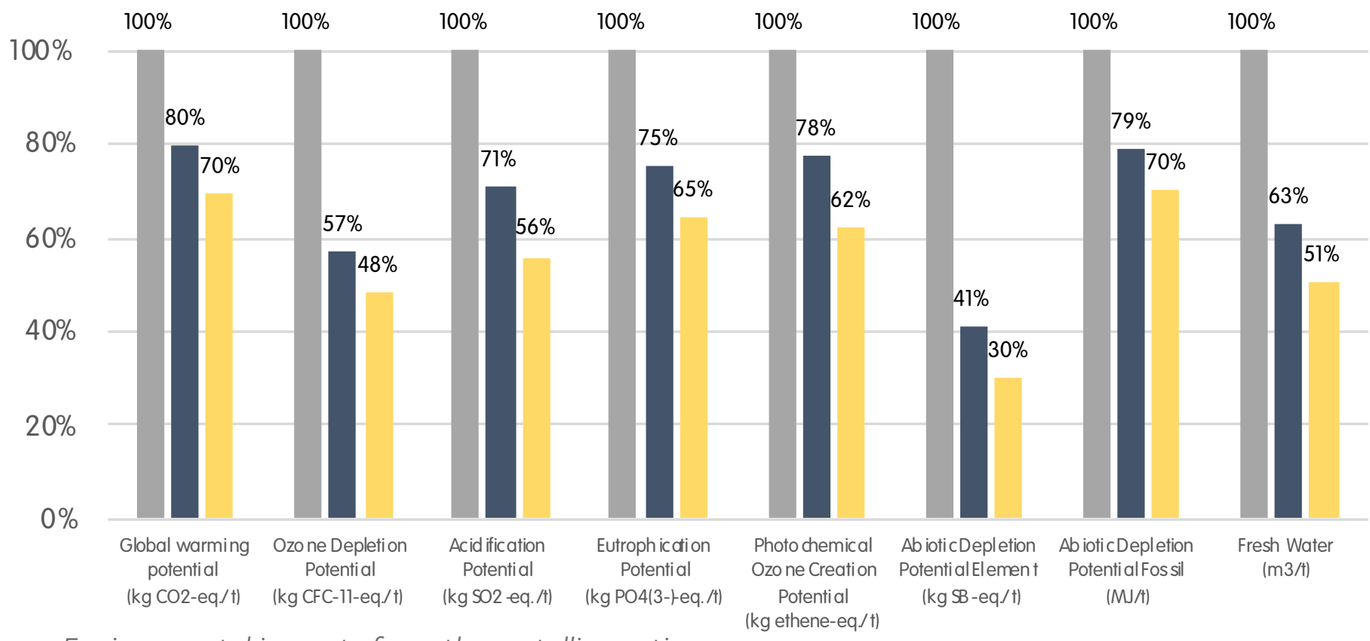
Environmental impact and other benefits

A comparative life cycle assessment of Magnelis® with equivalent functionality to a batch galvanised solution was conducted.

Data is based on ArcelorMittal EPDs for Magnelis® and pure-Zn galvanised coils. Hot dip galvanisation process data was used as a proxy for the batch process.

Since 2021, XCarb® green steel certificates allow customers to report an equivalent reduction in their Scope 3 emissions, in accordance with the Greenhouse Gas Protocol.

Environmental impact of coating during A1 to A3 lifecycle modules for 1 tonne of metallic coated steel



Environmental impacts from the metallic coating.
Comparison of a 2 mm steel substrate expressed for 1 tonne of coated steel.
Post-galvanised product used as 100% reference.

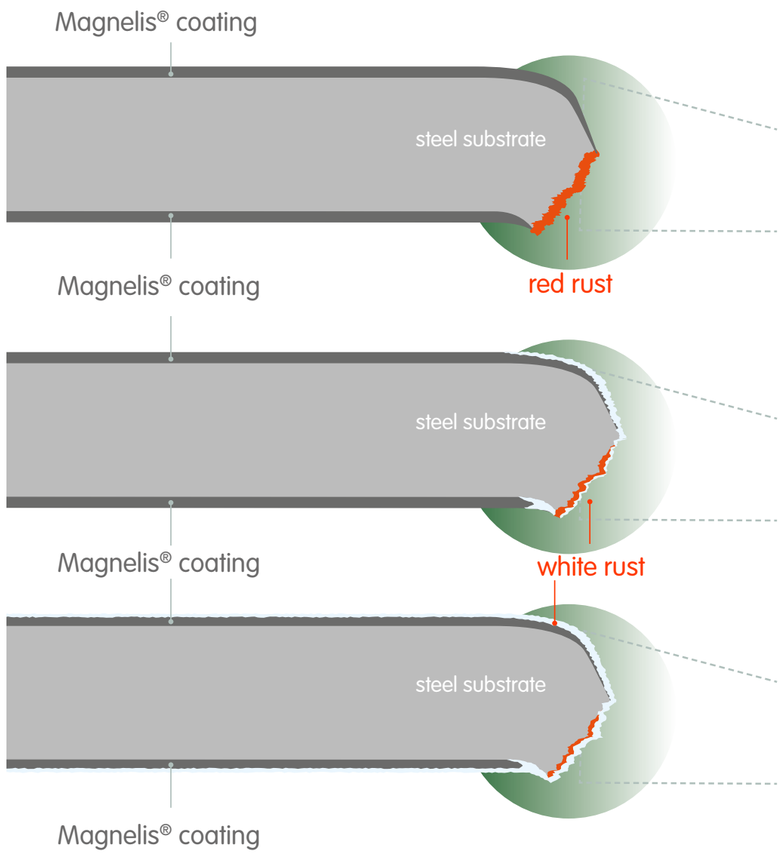
Additional benefits of Magnelis®

- On-line controlled
- Cost reduction (zinc, transport, human resources, etc.), especially when outsourced
- Availability: no limit on capacity
- Better geometrical tolerances (especially for thin gauges)
- No design constraints (holes, hollow sections, etc.)
- Smooth surface
- Compatibility with all high strength steels (EN 10346)

Cutting

Whatever the cutting process, Magnelis® and galvanised steel can be cut using similar parameters.

Magnelis® offers protection on cut edges and perforations thanks to its inbuilt self-healing properties.



Edge protection with self-healing effect

When exposed to the environment, Magnelis® forms a very dense zinc-based protective film, unlike galvanised where the film is very porous.

This unique dense film is also formed on edges, welds, perforations and scratches. In case some red rust was present on these uncoated zones, the red rust will be gradually covered by the Magnelis® film.

It is almost impossible for the environment to penetrate this film. The result is that Magnelis® provides perfect protection of the whole structure, even on the uncoated edges, scratches and perforations.

Initial exposure period (up to several weeks)*

The exposed cut end of the substrate is oxidised and forms red rust.

Subjected to rain and condensation (beyond several weeks)*

The zinc-based film containing magnesium on the coating layer migrates over the cut end.

Long exposure period (after more than a year)*

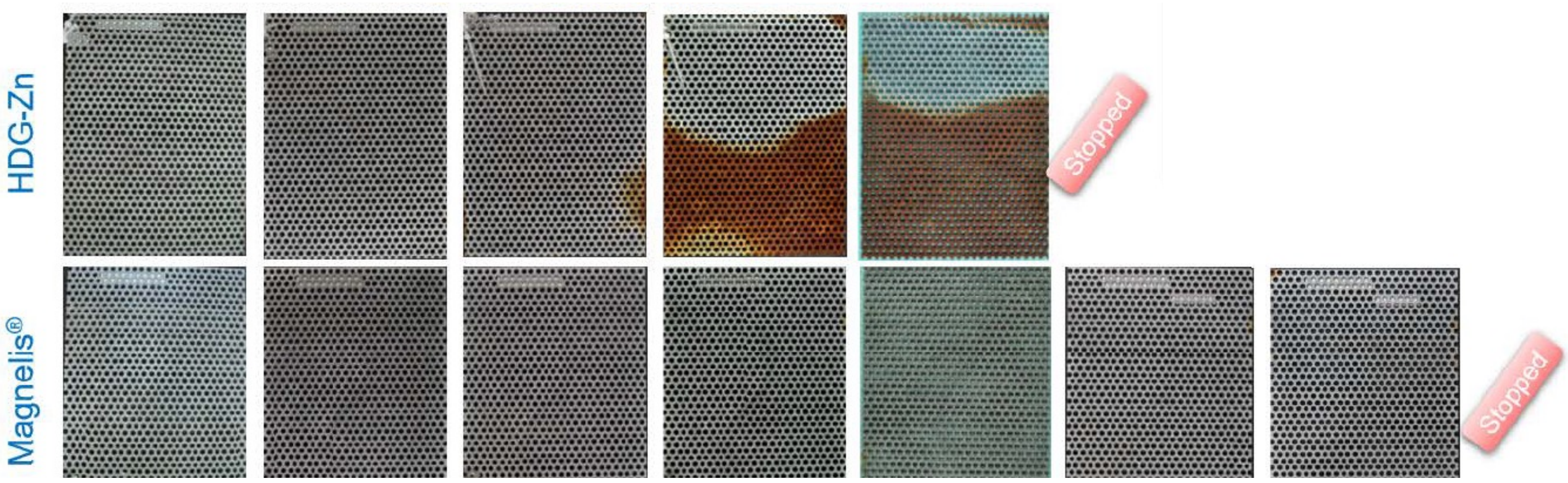
Disappearing of red rust and increasing of white rust.

** The speed of the self-healing may depend on the environment.*

Cutting

When parts have perforations, Magnelis® increases durability due to the self-healing effect.

The images show the results of outdoor exposure test results on perforated Magnelis® and galvanised parts.
The tests were conducted over 10 years in a severe marine environment.



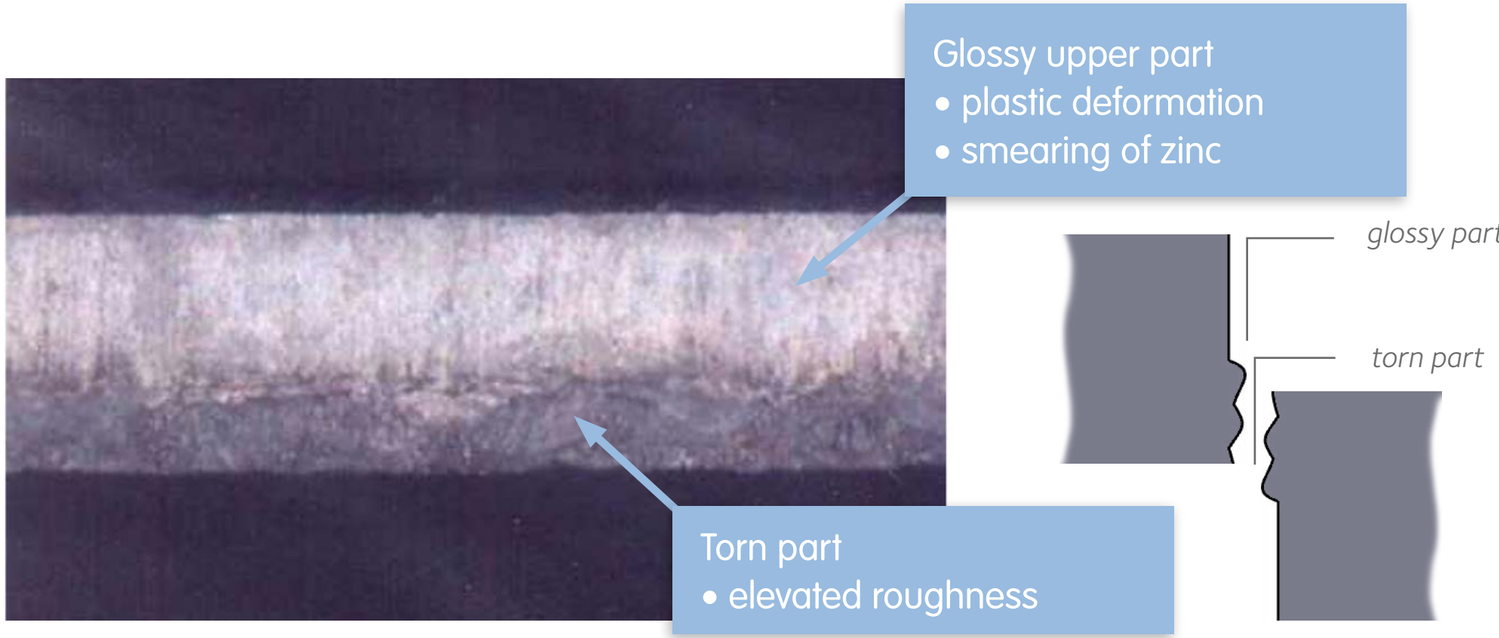
Perforated panels R4T6 - Exposure in Brest (F) 20 microns of each coating on a 2 mm substrate

Cutting

Shear cutting

If shear cutting is used, some of the Magnelis® coating from the surface is ‘spread’ over the edge. The spread of particles also occurs when galvanised material is shear cut.

The spread of Magnelis® helps to protect the uncoated surface against corrosion.
With galvanised steel, the similar spread leads to a lower protection due to the less resistant coating.



Cutting

Laser cutting

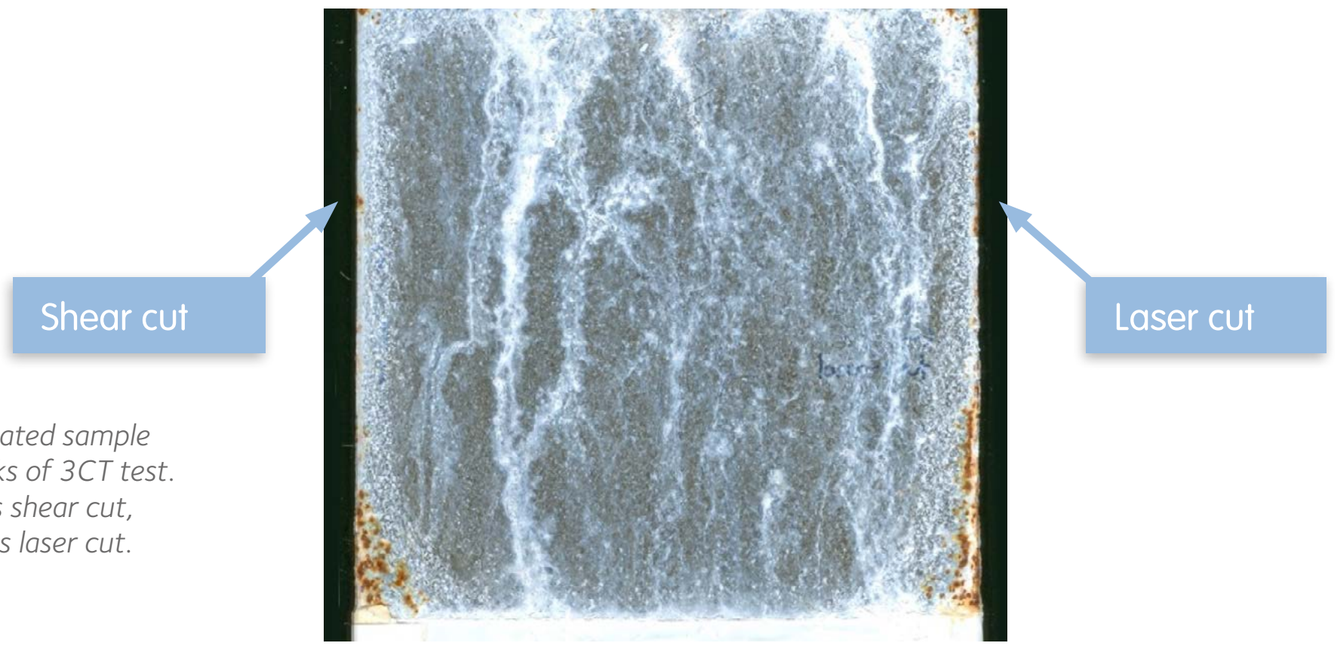
Some tests were done on a 5 mm thick steel sheet with a Magnelis® coating (ZM310 + E-Passivation®).

Laser cutting parameters during these tests were:

- Laser head: 7.5 mm
- Nozzle: 2.3 mm
- Gas: Nitrogen
- Power: 6000 W
- Speed: 2.72 m/min
- Gas pressure: 19 bar
- Distance from nozzle to sheet: 1 mm

During the laser cutting process, no significant difference is observed when Magnelis® is compared to laser cut galvanised steel of a similar thickness. There are slightly more fumes and a slightly larger burr with Magnelis®.

Laser and shear cutting was conducted on the same Magnelis® sample. After cutting, a 3CT cyclic corrosion test was performed to compare the laser cut and shear cut edges. After 33 weeks of testing, overall corrosion performance was comparable on both types of edges. This is due to the self-healing effect exhibited by Magnelis® which protects uncoated edges.



Magnelis® coated sample after 33 weeks of 3CT test. Left edge was shear cut, right edge was laser cut.

Cutting

Self healing

From the various outdoor exposure tests performed on Magnelis® over the years, it appears that the kinetics and aesthetics of the self-healing effect vary depending on the environment.

Although red rust may appear on the edges, no red rust is present on the surface near to the edges. This confirms that the corrosion protection provided by Magnelis® is very effective.

Cutting

DiBt certification-edges

The German Technical Approval for Magnelis® in building structural applications requires a 'corrosion allowance' to be included in the design of thick structural parts:

If you are designing a structural part for the highest durability (50 years) using a Magnelis® coated steel that is thicker than 3 mm, the width of the profile must include:

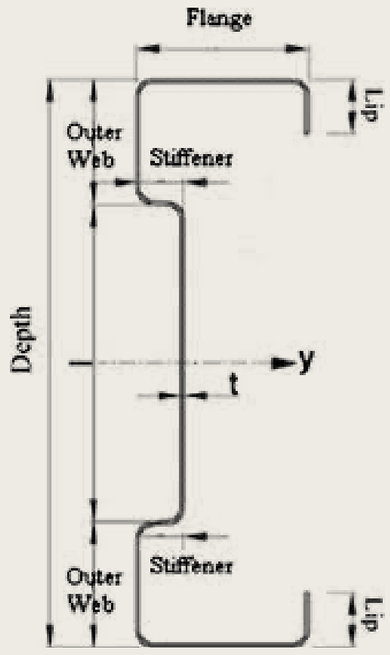
- 1 mm on each edge for a C2 environment
- 2 mm on each edge for C3 up to C5 environments

This additional safety margin was included by DIBt for the worst-case scenario (ZM310 on 6 mm for 50 years durability in a C5 environment).

Example of
'corrosion allowance'
on a Sigma 20012 profile

In a **C2** environment:
Lips: 20 mm + (2 X 1 mm) = 22 mm
> Width of the slit coil:
from 487 to 489 mm (+0.4%)

In **C3-C5** environments:
Lips: 20 mm + (2 x 2 mm) = 24 mm
> Width of the slit coil:
from 487 to 491 mm (+1.0%)



y–y is geometric axis of cross-section

Nominal cross-section dimensions for sigma sections

Section code	Depth (mm)	Flange (mm)	Lips (mm)	Outer-web (mm)	Stiffener (mm)	Thickness (mm)
Σ20012	200	62.5	20	45	16	1.2

Profiling, bending, and deep drawing

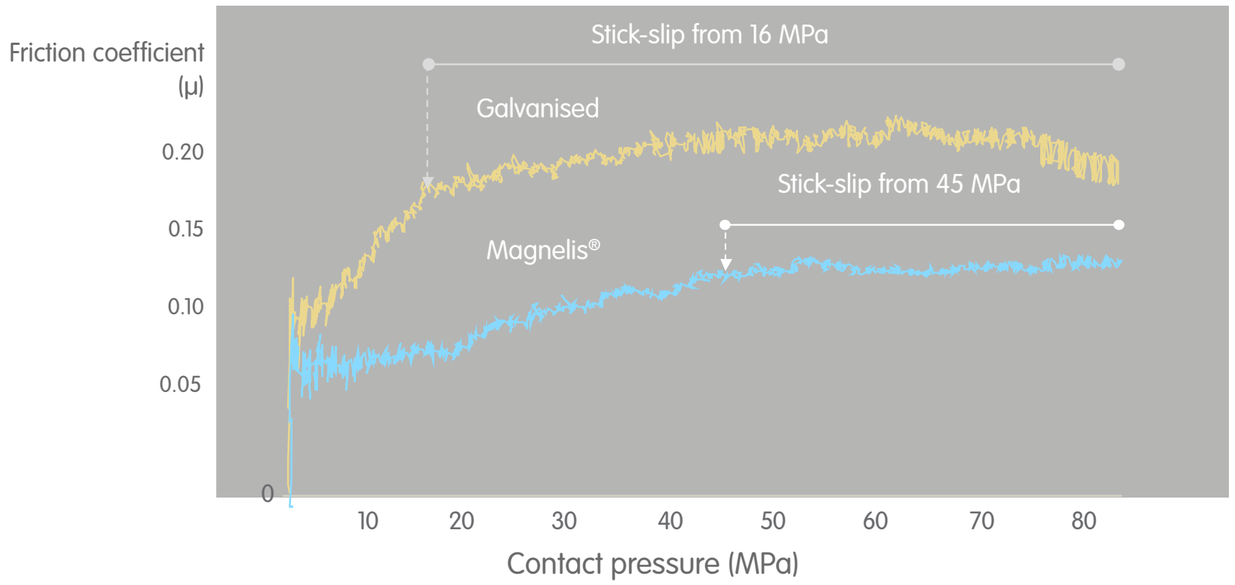
When using Magnelis®, very little adjustment is required to the set-up of forming tools used to process galvanised steels. Magnelis® has a lower friction coefficient than galvanised material, resulting in less powdering. The harder surface of Magnelis® also reduces the occurrence of scratching.

During forming operations, Magnelis®:

- Minimises pollution of forming tools such as profiling rolls
- Reduces the cleaning frequency and overall maintenance of manufacturing tools
- Reduces – and in some cases eliminates – the need for lubricants.

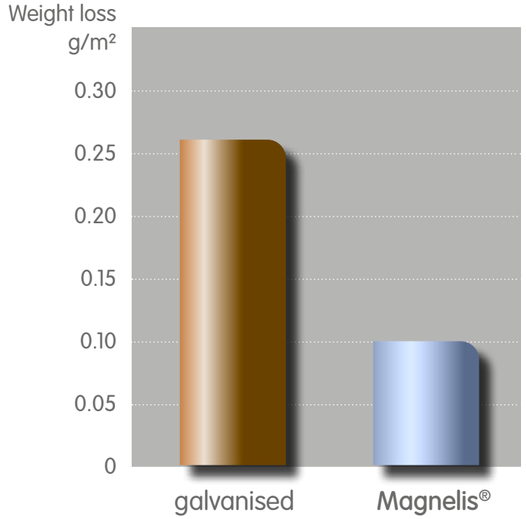
Friction test

Magnelis® offers improved friction behaviour.



Powder behaviour comparison

Magnelis® reduces the powdering behaviour.

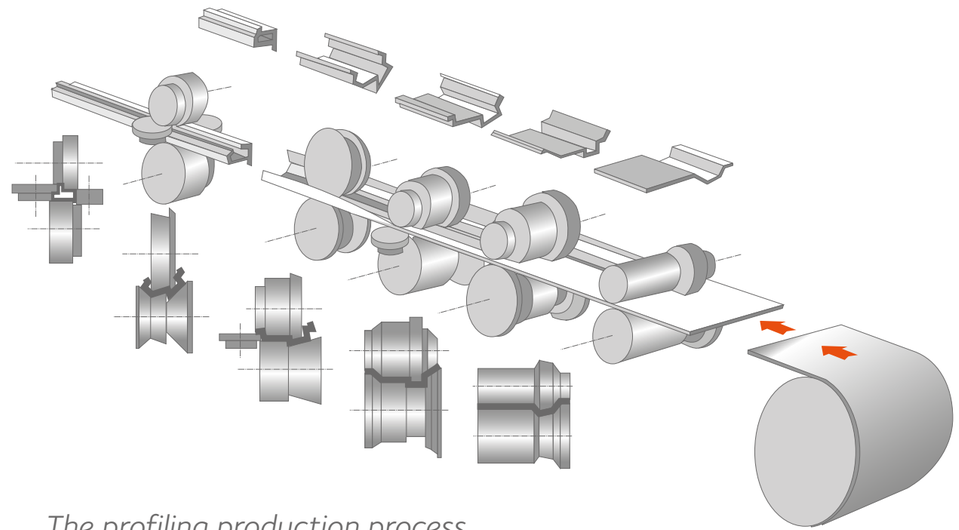


coating thickness 7.5 µm

Lubrication Oil Fuchs 41075 in excess
Source: ArcelorMittal Global R&D

Profiling and bending

Corrosion behaviour of bent area



The profiling production process

Magnelis® 10 µm on 0.7 mm 0T bending

After 4 months salt spray test

After 1 year outdoor exposure

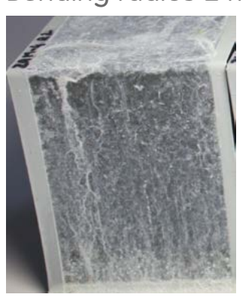
After 5 years outdoor exposure

Magnelis® 10 µm with three bending radii (2, 4, 6 mm)

Comparison with 10 µm hot dip galvanised (HDG) steel
Results after 10 cycles (VDA 621/415)

Omega-shaped profiles which are de-oiled, ungreased, and non-passivated.

Bending radius 2 mm



Magnelis 10 µm

HDG 10 µm

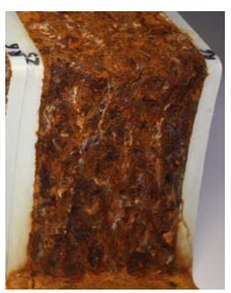
Bending radius 4 mm

Magnelis 10 µm

HDG 10 µm

Bending radius 6 mm

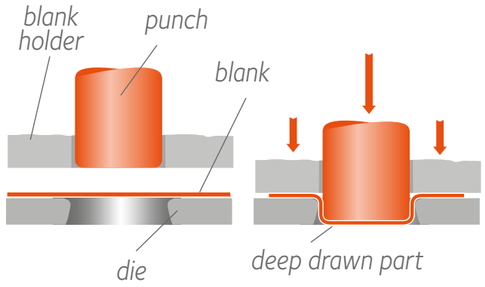
Magnelis 10 µm



HDG 10 µm

Deep drawing

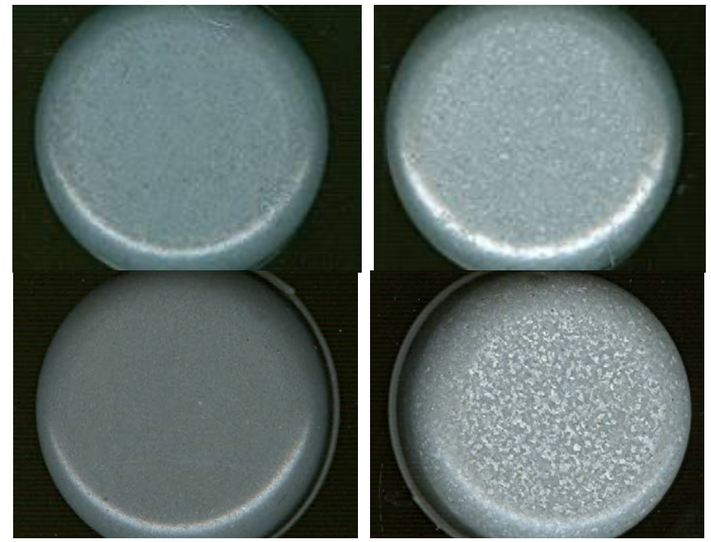
Corrosion behaviour of deep drawn area



The deep drawing process

Salt spray results

Outdoor results (Zelzate, Belgium)



Joining

Welding

Most welding processes can be used on steels coated with Magnelis® including: GMAW, TIG, HFI, spot, laser, and plasma.

The welding set-up parameters used for Magnelis® are similar to those used for galvanised steels.

These include:

- Maintaining a gap for the Zn vapour to escape
- Use of special consumables for GMAW to reduce porosity and spatter
- Installation of a fume extraction system.

During welding operations, Magnelis®:

- Consumes less energy and produces fewer fumes thanks to its thinner coating
- Can reduce reactive gas consumption during MAG welding
- Offers increased productivity (welding speed)
- Minimises the use of consumables including filler wire, reactive gas, and energy
- Meets health and safety guidelines.

Joining

Welding

HFI welding

(often used for making tubes)

Can be performed without prior removal of the Magnelis® coating

MIG/MAG welding:

Can be performed without prior removal of the Magnelis® coating.

Use of Galva Citoflux or Zn Safdual wires recommended.

For welding to a stainless part, use an AISI309 solid wire.

Plasma welding:

Can be performed without prior removal of the Magnelis® coating.

Higher welding speed achievable compared to galvanised material.

Laser welding:

Can be performed without prior removal of the Magnelis® coating.

A gap should be left between the parts to let the coating vapour escape.

Spot welding:

Electrode lifetime is equivalent to galvanised material when welding material of the same thickness.

Joining

Welding

In terms of health and safety,
welding Magnelis® is similar to welding,
for example, a galvanised coating:

- Fume emissions are similar to zinc-coated steel
- No new dangerous compounds are formed
- No over-concentration of Mg or Al.

Consequently, welding safety measures (such as adequate local fume extraction and provision of fresh air in the welding area) are similar.

Joining

Mechanical assembly (galvanic coupling)

- As the corrosion potential of Magnelis® and fasteners coated with Zn-based coatings (such as batch galvanised, electrolytic Zn coated, and Zn lamellar coatings) is close, no significant galvanic coupling effect is expected with these materials.
- For stainless steel fasteners, we recommend avoiding direct contact in environments with a corrosivity level higher than C3. This is due to the limited current density between both materials. Direct contact can be avoided by adding a polymer washer, an insulating material, or **another solution that avoids direct contact**.
- Magnelis® in direct contact with aluminium performs better than galvanised material.

The galvanic coupling behaviour of Magnelis® and aluminium assemblies in confined zones has been compared to that of galvanised/Al assemblies in a VDA 233-102 cyclic corrosion test. Measurement of corrosion depths after 15 weeks of testing revealed that both the mean and maximum corrosion depths on aluminium are significantly reduced when **Magnelis® is in contact with aluminium instead of galvanised material**.

- Direct contact between Magnelis® and copper (Cu) should be avoided (as for galvanised material). Magnelis® is anodic to Cu and will corrode preferentially and be consumed rapidly if they are in direct contact.
- The most critical material is lead (Pb). Direct contact must be avoided due to the very high current density between Magnelis® and Pb (as for galvanised material).

Joining

Adhesive bonding

Several glue types were tested on Magnelis® + E-passivation® including:

- One-component, elastic-based, silane modified polymer sealant
- Two-component elastic-based, silane modified polymer adhesive
- Epoxy
- Polyurethane
- Polysulphide

The tensile strength of these assemblies were tested:

- Before ageing (minimum 48 hours of hardening)
- After a constant-humidity condensation test according to NBN EN ISO 6270-2 (CH)
- After a cyclic corrosion test (CC).

The performance of all the glues mentioned was satisfactory for Magnelis® + E-passivation®.

The type of 'failure' after the CH and CC tests was almost always cohesive, not adhesive. That indicates that the failure occurs within the glue. This is considered to be the best behaviour in terms of adhesion properties.

However, each gluing application is a specific case.

Painting

For post-painted parts made with Magnelis®, better paint adhesion is expected. This reduces the need for maintenance of the final product.

In many cases, the use of Magnelis® can avoid the need for post-painting. This leads to cost savings and productivity gains.

"Previously, our silos were made from galvanised plates. Using Magnelis®, we noticed a positive difference in quality and the speed of production as no post-treatment was required.
We have many requests for urgent work.
If we use Magnelis®, the material is well protected against corrosion immediately. Magnelis® is an excellent addition to the existing range at MCB/Martens. In addition, working more efficiently and delivering quality fits perfectly with our company philosophy."

Wim Martens, construction and welding company Martens/ MCB, Someren (The Netherlands)

Painting

Lab tests

A post-painting test was conducted using paints that are known to be sensitive to adhesion.

The following materials were tested:

- Two substrates (galvanised (Z) and Magnelis®) each with two surface treatments: oil and E-Passivation® (EP)
- Three post-treatments before paint application: degreasing, Fe phosphatising, and Zn phosphatising.
- Three paints: polyester (red), epoxy-polyester (white), and polyurethane (black).

After painting, all samples were tested for corrosion resistance using a salt spray test. Each sample had a scratch on the surface and an unprotected edge.

The results showed:

- Magnelis® (oiled or with E-Passivation®) is effective for corrosion creep around the scratches and for protection against red rust on damaged parts.
- Magnelis® is more effective in protecting against red rust on damaged parts compared to HDG.

If Magnelis® is placed in a phosphate bath:

- Iron phosphate layer will have comparable weight to that of zinc
- Zinc phosphate layer will be lower compared to zinc (and to cold rolled steel)
- Almost no phosphate layer is deposited on the passivated substrate, not even when a pickling operation is done before the phosphatising process

On Magnelis® with E-Passivation®, it is better to avoid surface treatment processes for delamination.

The best results are obtained by post-painting directly onto the passivated Magnelis® surface.

It is recommended that a trial is conducted to evaluate adhesion performance. Trials should be conducted on every different paint application.

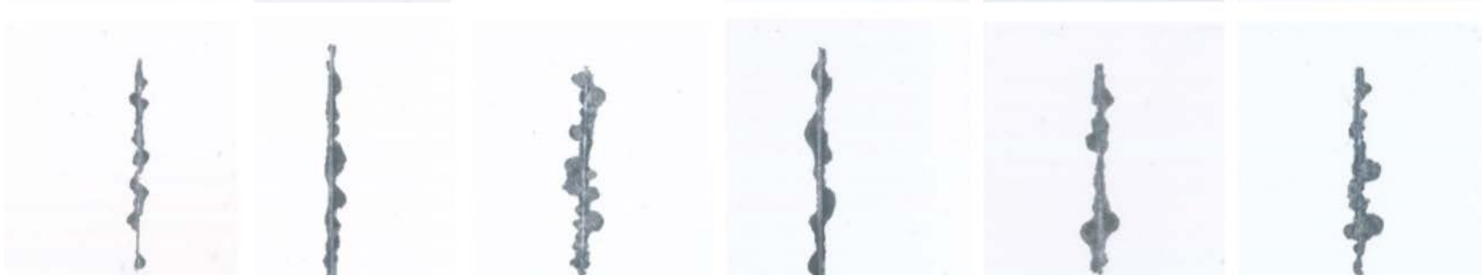
Painting

When Easyfilm® is applied, direct painting can be carried out without pre-treatment.

Light degreasing is recommended to remove any traces of dust or oil.

Corrosion resistance of painted parts:

- Reduced delamination for Magnelis® coated with Easyfilm®
- Delaminating area does not show white rust on Magnelis® coated with Easyfilm®.

Sample\Time	critical construction paint			critical appliance paint		
	120h SST	240h SST	500h SST	120h SST	240h SST	500h SST
Magnelis® + Easyfilm®						
Galva + Easyfilm®						

Results are indicative, but not universal.
Customer trials are always advised.

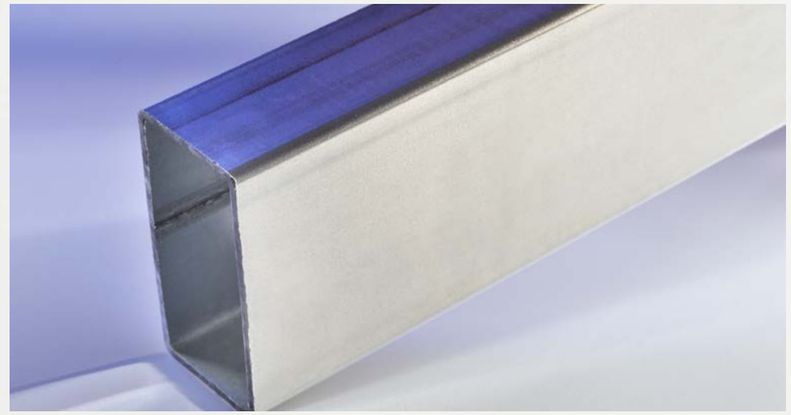
Welding

Magnelis® is compatible with High Frequency Induction (HFI) welding. Welding can be carried out without prior removal of the Magnelis® coating.

Welding parameters for Magnelis® are similar to the parameters for welding galvanised material.

Due to its increased durability, the coating thickness of Magnelis® can be reduced and will provide the same corrosion resistance as a thicker layer of galvanisation. Reducing coating thickness also cuts the risks of sputters and porosities during welding. Tube-making productivity can be increased.

See our specific health and safety guidelines for welding.



Welding

As with other types of coating, Magnelis can be damaged or removed in the weld zone due to the heat generated. This can compromise corrosion performance.

Depending on the application, corrosion protection may still be sufficient thanks to the self-healing effect of the Magnelis® coating. If not, thermal spraying can be used to re-protect the weld zone.

On tubes, the most common thermal spraying technique is wire arc spraying.

The wires which are most suitable for re-protecting Magnelis® tubes are:
Al, Al/Zn alloy (for example, 85/15%), or
Zn. ArcelorMittal has observed that the best performance comes from systems which contain Al.

The recommended re-protection thickness depends on the initial thickness of the Magnelis® coating, and on environmental conditions.

Before re-protection (as for other coated products), a suitable surface preparation process should be carried out. To achieve a re-protection layer with good performance, the surface to be re-protected should:

- Be clean, dry, and free from oil/grease and oxides, paint, salt, dirt, weld fluxes/splatters, and other possible contaminants.
- Have a certain level of roughness to promote better adhesion.

Note: In most cases, detailed surface preparation instructions are available in the technical datasheet of the re-protection products.

Protection performance

Comparison with tubes in pre-galvanised steel

Lab tests were performed to compare the corrosion resistance of Magnelis® coated tubes with pre-galvanised Zn coated material. Both samples were HFI welded.

During tube processing, the metallic coating on each tube was removed mechanically prior to welding.

Note: The prior removal of the coating is not a mandatory step in the tube process.

Sample descriptions:

Magnelis® (coating around 10 µm) with 85% Zn - 15% Al re-protection

Magnelis® (coating around 10 µm) with Al - Al re-protection

Magnelis® (coating around 10 µm) without re-protection

Pre-galvanised (coating around 20 µm) with and without re-protection

Protection performance

Comparison with tubes in pre-galvanised steel

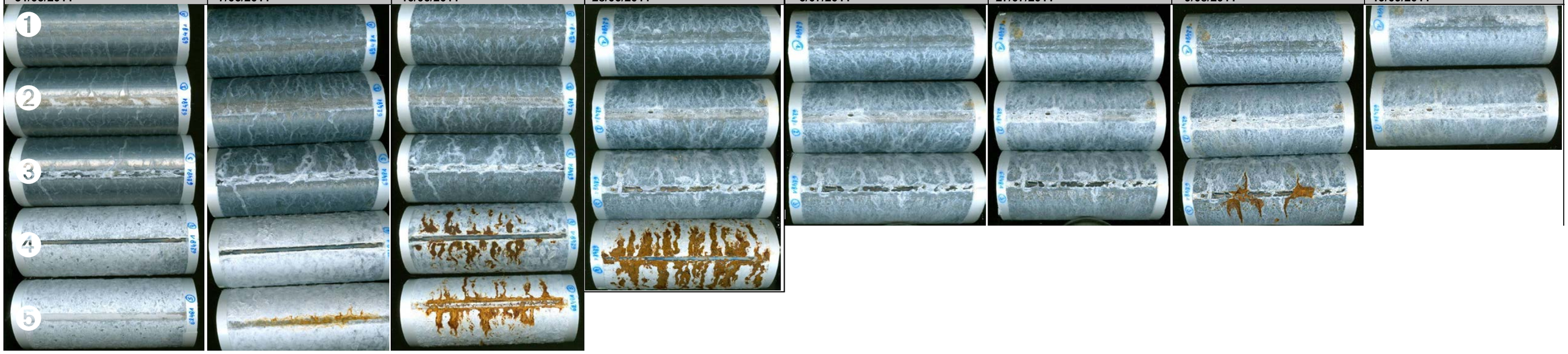
❶ Magnelis® 10 µm
with 85% Zn - 15% Al re-protection
❷ Magnelis® 10 µm
with Al - Al re-protection
❸ Magnelis® 10 µm
without re-protection
❹ HDG 20 µm
without re-protection
❺ HDG 20 µm
with Al – Al re-protection

Samples were compared after salt spray tests.

From this lab test, we can conclude that:

- Tubes with a 10 µm Magnelis® coating have much better resistance to the test than those with a 20 µm galvanised coating
- Both Zn-Al and Al-Al re-protection is compatible with the Magnelis® coating. Aesthetic aspects differ (dark or light grey).
- An Al-Al reprotection is not recommended on galvanised material due to galvanic coupling. However, it is very compatible with Magnelis®.

24h SST = 1day	192h SST = 8 days	408h SST = 17 days	696h SST = 29days	888h SST = 37 days	1392h SST = 58 days	1704h SST = 71days	2688h SST = 112 days
31/05/2011	7/06/2011	16/06/2011	28/06/2011	6/07/2011	27/07/2011	9/08/2011	19/09/2011



Protection performance

Comparison with tubes in post-galvanised steel

Additional lab tests were performed to compare the corrosion resistance of Magnelis® coated tubes with post-galvanised tubes using a standard salt spray test. Both samples were HFI welded.

On the welded and heat-affected area, the Magnelis® coated tubes were re-protected. Using salt spray tests, Magnelis® ZM310 was compared to post-galvanised samples with a 55 µm coating.

The results of the tests show that Magnelis® ZM310 exhibits **at least the same corrosion resistance as a 55 µm post-galvanised coating**.

Tubes coated with Magnelis® ZM310 offer much better corrosion resistance during salt spray tests than post-galvanised tubes.

Magnelis® ZM310

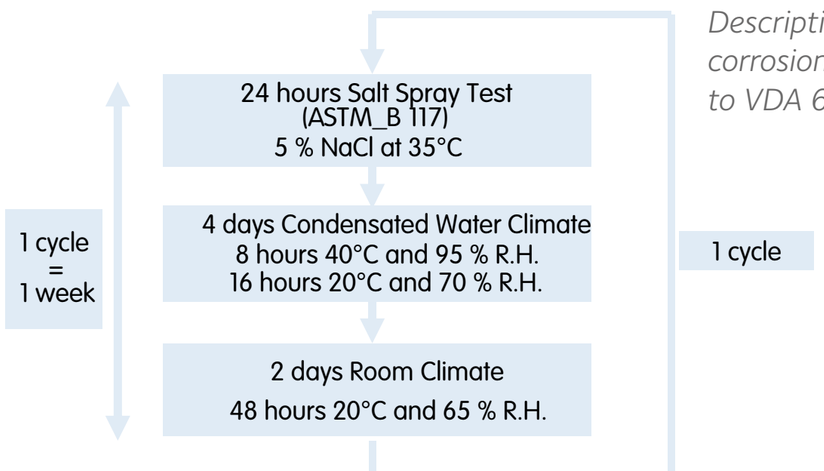
Non welded | Welded and re-protected

Visual aspect after 25 weeks

Post-galvanised 55 µm

Non welded | Welded

extracted after 10 weeks



Description of the cyclic corrosion test (3CT) according to VDA 621-415.

Protection performance

Comparison with tubes in post-galvanised steel

Additional lab tests were performed to compare the corrosion resistance of Magnelis® coated tubes with post-galvanised tubes using a cyclic test (VDA 621-415). Both samples were HFI welded.

On the welded and heat-affected areas, the Magnelis® coated tube were re-protected. In these tests, Magnelis® ZM310 was compared with post-galvanised samples with a 55 µm coating.

The results show that Magnelis® ZM310 offers at least the same corrosion resistance as a 55 µm post-galvanised coating.

Tubes coated with Magnelis® ZM310 offer much better corrosion resistance during cyclic tests than post-galvanised tubes.

Magnelis® ZM310

Non welded | Welded and re-protected

Visual aspect after 33 weeks

Post-galvanised 55 µm

Non welded | Welded

Visual aspect after 33 weeks

Standards

Magnelis® coated steel can be used to produce tubes according to the following standards:

- EN 10305-3:2016 for steel tubes (circular) for precision applications
- EN 10305-5:2016 for steel tubes (square and rectangular) for precision applications
- EN 10219-3 for steel tubes used for mechanical engineering purposes.