David Harrison, Bronx International

Galfan®—Low Cost, High Performance Metallic Coating
Bronx Metal Coating Lines, can be designed for:

- Galvanize
- Galfan
- Galvalume

• Each coating type has unique product attributes and relative advantages, depending on the end-use application

• However, for customers wanting similar corrosion protection at reduced coating mass, in painted or formed applications, Galfan may be the solution
What is Galfan?

• 95% Zn 5% Al, 0.05% mischmetal
  – MM = rare earth elements, improve wetting & corrosion resistance

• Eutectic alloy
  – lowest melting point of any Zn Al composition
  – Lamellar microstructure – high zinc phase and high aluminium phase freeze into thin alternating plates.
  – It is this microstructure which is key to Galfan’s unique benefits around corrosion resistance and ductility
## Coating Microstructures

<table>
<thead>
<tr>
<th>Coating Type</th>
<th>Microstructure Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot-Dip Galvanized Coating (GI)</td>
<td>Zinc overlaying a Fe₅Al₃ intermetallic layer</td>
</tr>
<tr>
<td>Galfan Coating (GF)</td>
<td>Zinc and aluminium lamellae with a negligible intermetallic layer FeAl₃ 10-20 nm</td>
</tr>
<tr>
<td>Galvalume Coating (GL)</td>
<td>Zinc rich matrix, Aluminium rich dendrites, Silicon crystal, Intermetallic layer AlZnFeSi</td>
</tr>
</tbody>
</table>
Galfan Development

– Developed around 1980 at the Centre de Recherche's Metallurgies (CRM) in Belgium under the sponsorship of The International Lead Zinc research Organization (ILZRO)

– First industrial trial was at Ziegler in Mouzon (France) in 1981
The development aim of Galfan was to improve the corrosion resistance of Galvanize while keeping its key features:

- Good sacrificial protection by Zinc
- Good formability
- Acceptable weldability
- Good paintability in coil coating

The development outcome was improved corrosion resistance, sacrificial protection, formability and paintability.
Why Now

• Galfan is not a new coating, it has been widely adopted and incorporated in many international standards (ISO, JIS, ASTM, AS).

• Galfan coil production in Europe continues at several Arcelor Mittal facilities in both Belgium and France, at TKS in Germany, at Tata Steel in North Wales and Rautaruukki Finland; as well as in the US, and several Asian countries.

• No Galvalume production now in Europe except at Arbed in Luxembourg (Arcelor Mittal)
Why Now Continued

• At the time of its introduction, Galfan was generally produced at similar coating weights to regular galvanize, and was slightly more expensive to make due to the ingot alloying premium.
• It was promoted as a premium product and offered at a premium price.
• Producers found it difficult to command higher prices, except from customers with special requirements, e.g. those requiring the excellent combination of forming and corrosion resistance in painted Galfan sheet, where tension bends are used, or for highly formed parts such as deep drawn auto parts.
• There was little industry focus at that time on LCM applications.
Why Now Continued

• Over time we have seen market growth in painted coil products.
• Line speeds have also increased, making low zinc coating weights more difficult to achieve.
• An increasing number of steel companies are buying the pre-alloyed CG alloy (Zn-Al) for use on GI lines.
• Continued focus on material costs and the drive for sustainability have pushed many companies to look for alternative coating chemistries or to lower zinc coating weights.
• The unique corrosion and paintability benefits, low cost, and the relative ease of production made Galfan a perfect choice for today's market.
The Case for Galfan

• Corrosion Mechanism – How Zn protects steel
  – Barrier Protection
  – Sacrificial / Galvanic / Cathodic Protection

• Properties of Galfan®
  – Paintability
  – Ductility / Formability

• Why Not Galvalume® or Mg containing alloys?

• Processing Attributes of Galfan®

• Low Coating Mass Metallic Coatings

• Conclusion
Why Use Zinc Coated Steel - Corrosion Protection

• Steel corrosion rate is 10-100 greater than zinc (depending on the environment)

• Zn Provides a physical **barrier** to corrosion of the underlying steel substrate

And

• **Galvanically protects the steel** (acts as sacrificial anode)
  - If the barrier coating is compromised, i.e. bare spots, cut ends or small holes, the zinc will corrode in preference to the steel
  - Important property for painted galvanized steel
Barrier Corrosion Protection

- It is well known that alloying Aluminium with Zinc reduces the corrosion rate, compared to Zinc.

- But why is this so?

- The answer lies in the thin film of corrosion products that form on the zinc alloy surface.
• Corrosion rate of Zinc Aluminium coatings slow over time as the surface becomes enriched in more stable aluminium-containing corrosion products
• Corrosion Resistance of Galfan is (at least) twice that of regular Galvanize, recognised in ASTM standards and by Underwriters Laboratory
• The decrease in corrosion rate with time is stated in ASTM A875/SA875M and has been referred to as the Galfan Performance Ratio (GPR),
• The GPR increases with exposure time as seen in this diagram. It shows Galfan as being twice as effective as heavy galvanized at 8-1/2 years, 2-1/2 times better at 15 years, 3 times at 25 years and almost 4 times better at 50 years.
Atmospheric Exposure - Marine Environment

Coating Corrosion Loss (g/m²)

<table>
<thead>
<tr>
<th>Period of Exposure (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Zinc</td>
</tr>
<tr>
<td>Galfan (Zn 5Al)</td>
</tr>
</tbody>
</table>

Nisshin Steel Data

Zn corrosion rate is largely linear with time

5Al corrosion rate decreases with time
Bronx Corrosion Exposure Testing

- 5 Year atmospheric corrosion exposure test of ZA alloy coatings in a severe marine environment – confirmed the excellent corrosion resistance of Galfan
- New test programme, specifically looking at Low Coating Weight products (GI, GF & GL)
Sample Appearance after Exposure for 1851 Days at Belmont Beach, Severe Marine Site

5 Year Corrosion Exposure Test, with Teck, Galvatech 2015
Neutral Salt Spray Test – Also Demonstrates GPR

Coating Weight (g/m²)

Zinc

Linear

Galfan

Hours to Reach 5% Red Rust

Centre de Recherches Métallurgiques-Abbayedu Val-Benoit, Liege, Belgium (1987)
Cut-edge Protection / Galvanic Protection / Cathodic Protection

- Ability of the coating to protect the steel on cut-edges and around breaks in the coating
Galvanic Protection of Steel by Zinc – An Electrochemical Process

Galvanic corrosion of zinc - Anode
\[ \text{Zn} \rightarrow \text{Zn}^{2+} + 2e^- \]

Galvanic protection of steel – Cathode
\[ \text{O}_2 + 4\text{H}^+ + 4e^- \rightarrow 2\text{H}_2\text{O} \]
750 Days Exposure at Belmont Beach Corrosion in a Severe Marine Environment

Galvanic Protection of the exposed cut edge, 1.6mm gauge

Barrier protection of underlying steel
On pre-painted galvanized coil it is the galvanic protection provided by zinc which prevents undercutting of the paint.
Galvanic Protection & Aluminium

• Aluminium doesn’t offer the same protection as zinc because its surface becomes passivated, stopping the anodic reaction from protecting the steel substrate.

• High Aluminium content is the reason why Galvalume has good barrier protection but poorer cut-edge protection than Galvanize.

• But what about Galfan? It also contains Aluminium.
Cathodic Protection Zn versus Galfan

Electrochemical testing by Pagniez

– Initially Zinc provides a higher anodic current
– But Galfan provides protection over a longer period of time
  – Galfan is still providing cathodic protection after 800 hours
  – Cathodic protection stopped for Zn after 450 hours
Sample Appearance after Exposure for 1851 Days at Belmont Beach

Galfan demonstrates improved cut-edge protection over Zn

Top View of Cut-Edge 1.6mm GI HRC

5 Year Corrosion Exposure Test, with Teck, Galvatech 2015
Galfan versus Zinc or GI

Galfan has superior corrosion protection compared to GI

The superior corrosion protection of Galfan versus Galvanized gives the steel purchaser a choice: cut the coating weight in half for the same protection, or maintain the same coating weight and double the corrosion protection to achieve a premium product.
Galfan - Paint Adhesion

• Tested extensively in Europe, North America & Japan
• Uniform crystal orientation favours good paint adhesion
  – Skin passed Galfan has the best, i.e. most uniform crystal orientation of all the zinc aluminium coatings
• Galfan has reduced micro-cracking on formed bends
• Can be bent into sharp profiles without damaging the coating
• Galfan resists edge creep at cut-edges and red staining at fasteners
Improved Paint Adhesion Over Galvanize

Painting adherence / Combined test: Erichsen and impact

Ref GTC
Improved Corrosion Resistance of Painted Products Over Galvanize

Ongoing of White and Red Rust Measurements on Pre-painted, Bent and Scratched Samples

(Cockerill Sambre)
• Why Not Low Coating Mass Galvalume?

• Doesn't Galvalume have better corrosion resistance than Galvanize or Galfan?
Galvalume Corrosion Resistance

- Excellent barrier protection (atmospheric) – related to the labyrinth of zinc & aluminium rich areas in the microstructure.
- Barrier protection is compromised at low coating weights as the correct coating microstructure is not developed.

Target Galvalume Microstructure
Galvalume Corrosion Resistance Continued

- Not suitable for high pH conditions, e.g. contact with concrete or for use in intensive animal farming
- Sensitive to sharp bends
- Relatively poor cut-edge/galvanic protection (due to high Al content) – why GL is not available in heavy gauges
- Sensitive to prolonged water contact
Galvalume Coating Weights

- Galvalume suffers a step change decrease in performance at lower coating weights as the corrosion resistance is linked to the labyrinth of zinc & aluminium rich areas in the microstructure.
- Galvalume requires a minimum coating weight of 153 g/m² (both sides), AZ50, in order to develop its characteristic microstructure.
- At 107 g/m² (both sides) or less, i.e. AZ35, GL develops a “Bamboo” microstructure with greatly decreased corrosion resistance. An AZ35 coating is 1/3 the thickness of an AZ100 coating, but has 1/10 the corrosion resistance, depending on the environment - coating weights in this range are not endorsed by the BIEC.

“Bamboo” microstructure - Zn12Al coating
Corrosion occurs preferentially through the zinc phase
Why not Magnesium Containing Chemistries

• Adding magnesium to a Zn Al bath increases the corrosion resistance of the coating, good for applications requiring very high levels of corrosion resistance such as consistently wet salty conditions. Often promoted as a replacement for batch HDG.

• Decreases coating ductility/cracking resistance

• Can be problematic to paint, especially with non Cr\(^{6+}\) treatments. Eg may cause delayed adhesion issues without appropriate pre-treatment

• MgO formation can cause issues with bath management & air wiping
SEM Pictures of the Bend Surface in a 1T Bending Test

Galfan

ZAM

Super Dyma

After DeBruycker, PhD
Manufacturing Galfan

• Same process as Galvanize
• Easy conversion for existing GI producers
Bath Temperature

- Galfan has a 40 °C lower bath temperature than regular galvanizing
- Lower energy consumption than regular galvanizing
- Melting temperature of Galfan is only 380 °C, compared to ~580 °C for Galvalume
- Significantly lower energy consumption than Galvalume
Effect of Temperature on Steel Properties

- Jet cooling and holding sections of the NOF furnace are reduced in size compared to Galvalume.
- Over-aging temperature, at 440 °C for Galfan, is much better from a metallurgical standpoint than Galvalume:
  - Galvalume coated steel is always harder;
  - Easier to produce soft properties with Galfan compared to Galvalume.
Fast cooling is required for Galvalume to produce the correct microstructure and for the top roll temperature:

• Galvalume requires an air cooler after the pot;
• Galfan uses the same cooling system as Galvanize.
Pot Comparison

• Ceramic pot required for Galvalume, Galfan can use a 316L pot or ceramic.
• Galvalume suffers from pot inductor corrosion, whereas Galfan does not.
• Galvalume requires 3 to 4 inductors in the pot because of high entry temperatures, Galfan requires only 2.
The Corrosion of Pot Hardware in Galfan is Very Low

- Dissolution rate of 316L is low at 5% Al (+low bath Temp)
- Corrosion rate increases at low Al % (GI)
- Corrosion rate increases at high Al % and temp (GL), Si added to control the reaction

After Bright & Barbero
The Corrosion of Pot Hardware in Galfan is Very Low:

- With Galfan hardware can stay in the pot for 4-6 weeks;
- With Galvalume, hardware can only stay in the pot for 10-15 days, or less with poor bath Si control
- With Galvanize, hardware can stay in the pot for 10 to 21 days, or less with poor Al control or for dual GI/GA
Galfan has Reduced Dross Generation

• Galfan has a very low iron solubility – creating less dross than regular galvanize and no bottom dross.
• Unlike Galvalume, no dross build-up occurs on the sink roll:
  • Galvalume requires a roll scraper, Galfan does not.
• During line stops, Galvalume has a higher strip corrosion rate than Galfan
Dross Comparison, Galfan versus Galvanize

<table>
<thead>
<tr>
<th></th>
<th>Galvanize</th>
<th>Galfan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dross Make (g/m²)</td>
<td>13.4</td>
<td>8.5</td>
</tr>
<tr>
<td>Line Speed (m/min)</td>
<td>132</td>
<td>135</td>
</tr>
<tr>
<td>Strip Width (mm)</td>
<td>1100</td>
<td>1145</td>
</tr>
<tr>
<td>Strip Gauge (mm)</td>
<td>0.52</td>
<td>0.54</td>
</tr>
<tr>
<td>Coating Weight (g/m²)</td>
<td>163</td>
<td>184</td>
</tr>
<tr>
<td>Pot Temperature (°C)</td>
<td>459</td>
<td>425</td>
</tr>
</tbody>
</table>
No Pre-melt Pot is Required for Galfan – Ingots are Pre-alloyed:

• Bath Al content is not critical (same coating properties between 4.2-4.9% Al)
• No systematic pot analysis required
Achieving Low Coating Mass, Main Factors:

- Line Speed
- Viscosity of the melt / Chemistry
- Wiping force
Achieving Low Coating Mass - Limits

- There are physical limits on the achievable minimum coating mass
- The higher the line speed, the higher the coating mass
- The higher the liquid viscosity, the higher the coating mass
- Optimising the design of air knives can allow the manufacturer to lower coating weights but the physical limits on achievable LCM still remain
Fig 9: Relative cost Map for Gi, according to physical limits indentified

After Dubois, 2011
Galfan has a 10-16% (dependent on bath temperature) lower viscosity than Zn

- Down to 5 micron coatings achievable with good performance;
- Lower viscosity also allows for higher line speeds
- Less wiping pressure for the same coating weight
- Less noise, less ash
Zn versus Galfan Viscosity

Figure 3 Viscosity of common Zn-based alloys used in galvanizing and die casting.

After Liu
Relationship Between Strip Speed and Wiping Pressure

- Zinc 275 g/m²
- Galfan 255 g/m²

Krupp-Hoesch
Conclusion

Galfan allows the manufacturer to lower his manufacturing costs:

– Via the production of a minimum coating weight product,
– At maximum line speed,
– Without compromising the corrosion resistance of the product.
– Lower bath temperatures and less aggressive bath chemistries further reduce operating and maintenance costs.
Conclusion Continued

• For painted and formed products, Galfan offers further advantages around improved paint adhesion and coating ductility.
• For these reasons, Bronx has partnered with the Galfan Technology Centre to offer Galfan coatings on new and existing lines.
• Bronx will continue to build lines for GI and GL coatings to meet individual customer requirements.
Thank You!

Contact Details

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NSW 2210 Australia

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Website: www.bronxintl.com
Spare Slides
<table>
<thead>
<tr>
<th>Coating Attributes</th>
<th>Regular Hot-Dip Galvanize</th>
<th>Galfan (GF)</th>
<th>Galvalume (GL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>99.8</td>
<td>95</td>
<td>43.5</td>
</tr>
<tr>
<td>Aluminium</td>
<td>0.2</td>
<td>5</td>
<td>55</td>
</tr>
<tr>
<td>Silicon</td>
<td>0</td>
<td>0</td>
<td>1.4</td>
</tr>
<tr>
<td>Mischmetal</td>
<td>0</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>Formability</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Corrosion Resistance (unpainted flat panel)</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Sacrificial Protection of Bare Ends and Scratches</td>
<td>5</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Corrosion Resistance (unpainted, formed)</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Paint Adhesion</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Corrosion Resistance (painted, formed)</td>
<td>4</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Weldability</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Heat Resistance/Reflectivity</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Coating Weight/Face (g/m²)</td>
<td>33-300</td>
<td>30-215</td>
<td>75-105</td>
</tr>
<tr>
<td>Dependent on reference strip and line specification</td>
<td>33-300</td>
<td>30-215</td>
<td>75-105</td>
</tr>
</tbody>
</table>

5=best, 1=worst, Coating attribute data sourced from ILZRO.
Galfan Standards

• The ASTM steel sheet product specification for Zn-5% Al alloy-coated sheet is A 875/A 875M.

• The coating is available in two types: Type I alloy coating contains small additions of rare earth mischmetal (Zn-5Al-MM) and is what is used to produce sheet under the trade name Galfan®. Type II contains 0.1% magnesium (Zn-5Al-Mg). Zinc-5% Al alloy-coated sheet is also manufactured and sold under other trade names.

• Both Type I and Type II can be used for pre-painted sheet as specified in A 755/A 755M.

• AS1397 – 2011 now includes Galfan coatings (ZA coating class)

• Specifications EN 10327, EN 10214 and ISO 14788 are other documents that can be used to specify Zn-5% Al coated sheet.

• Galfan® ingot for preparation of the hot dip bath is addressed by ASTM Designation B 750-99

• JIS G 3118, “Pre-painted hot-dip zinc-5% aluminium alloy-coated steel sheets and coils

• JIS G 3317, “Hot-dip zinc-5% aluminium alloy-coated steel sheet and strip
Galfan Appearance

- Galfan does not have the traditional spangle of GI; it has a smooth reflective surface with faint hexagonal boundaries.
- Chromate passivated bare panels can darken over time
- Anti-fingerprint resin coating can be used to maintain lustre
Mischmetal

- An alloy of rare earth elements in various naturally occurring proportions. A typical composition includes approximately 50% cerium and 25% lanthanum
- 0.05% concentration in bath, pre-alloyed
- Improves wettability & eliminates bare spots
- Improves corrosion resistance if tramp elements are present
## Barrier Protection - Salt Spray Test

<table>
<thead>
<tr>
<th>Time</th>
<th>500h</th>
<th>1,200h</th>
<th>2,500h</th>
</tr>
</thead>
<tbody>
<tr>
<td>55% Al-Zn alloy coated steel</td>
<td><img src="image1.jpg" alt="Image" /></td>
<td><img src="image2.jpg" alt="Image" /></td>
<td><img src="image3.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Zn-5% Al alloy coated steel</td>
<td><img src="image4.jpg" alt="Image" /></td>
<td><img src="image5.jpg" alt="Image" /></td>
<td><img src="image6.jpg" alt="Image" /></td>
</tr>
<tr>
<td>Galvanized steel</td>
<td><img src="image7.jpg" alt="Image" /></td>
<td><img src="image8.jpg" alt="Image" /></td>
<td><img src="image9.jpg" alt="Image" /></td>
</tr>
</tbody>
</table>

**Appearance after salt spray test**

(SST: JIS Z2371)

(Coating weight on one side 0.30 oz/ft², no chem treat)

Nisshin Steel Data
## Cut Edge Corrosion

Appearance of cut edge sections after salt spray test
(Thickness 0.126", coating weight 0.40/0.40 oz/ft², no chem treat)

<table>
<thead>
<tr>
<th>Time</th>
<th>100h</th>
<th>1,000h</th>
<th>5,000h</th>
</tr>
</thead>
<tbody>
<tr>
<td>55% Al-Zn alloy coated steel</td>
<td><img src="image" alt="Image of corrosion after 100h" /></td>
<td><img src="image" alt="Image of corrosion after 1,000h" /></td>
<td><img src="image" alt="Image of corrosion after 5,000h" /></td>
</tr>
<tr>
<td>Zn-5% Al alloy coated steel</td>
<td><img src="image" alt="Image of corrosion after 100h" /></td>
<td><img src="image" alt="Image of corrosion after 1,000h" /></td>
<td><img src="image" alt="Image of corrosion after 5,000h" /></td>
</tr>
<tr>
<td>Galvanized steel</td>
<td><img src="image" alt="Image of corrosion after 100h" /></td>
<td><img src="image" alt="Image of corrosion after 1,000h" /></td>
<td><img src="image" alt="Image of corrosion after 5,000h" /></td>
</tr>
</tbody>
</table>

Nisshin Steel Data
The surface of Galfan also has a lower coefficient of friction compared to Galvanized, which is an added benefit in deep drawing applications.