BRONX INTERNATIONAL
Coil Coating Line Solutions

Galfan® - Low Cost, High Performance Metallic Coating

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Introduction

Bronx International provides Coil Coating Line solutions to steel and aluminium companies, worldwide. Bronx metal coating lines can be designed to produce Galvanized (GI), Galfan (GF) or Galvalume (GL) coated coil, according to individual customer requirements. Each of these coating types has unique product attributes and relative advantages, depending on the end-use application.

Globally, for painted coil applications there is a growing trend among manufacturers to reduce coating costs through lowering zinc coating weights, with some manufacturers seeking to apply the lowest possible coating mass.

This paper considers the relative performance of Low Coating Mass (LCM) Galvanize, Galfan and Galvalume coatings and identifies the benefits of Galfan, particular in painted applications.

Galfan

Galfan is a zinc aluminium alloy containing 95% zinc, 5% aluminium and 0.05% mishmetal (MM). Mischmetal is a naturally occurring mixture of rare earth elements which is added to improve wetting and enhance corrosion resistance. Galfan is a eutectic alloy and so has the lowest melting point of any zinc aluminium composition (around 380 ^{o}C). Galfan has a lamellar microstructure, consisting of thin alternating plates of high zinc and high aluminium phases with an extremely thin intermetallic layer (figure 1). It is this microstructure which is the key to Galfans unique benefits around corrosion resistance and ductility. The characteristic microstructure and thin alloy layer of Galfan are also beneficial in LCM applications, where achieving low coating weights is made easier by the low viscosity of molten Galfan.

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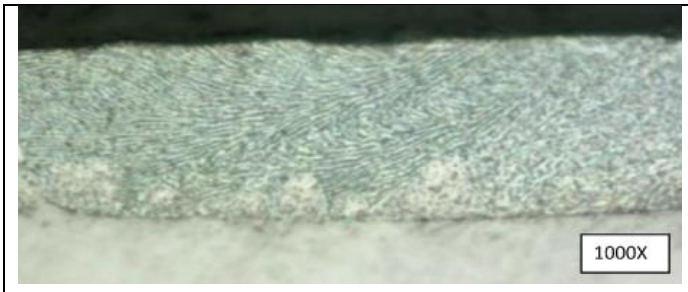

Figure 1. The microstructure of Galfan consists of thin alternating lamellae of zinc-rich and aluminium-rich phases, overlaying an extremely thin (10-20nm) $FeAl_3$ intermetallic layer.

Figure 2. Galfan has a smooth reflective surface with faint hexagonal boundaries.

The unique coating chemistry of Galfan also has an effect on its surface appearance. Galfan does not have the traditional snowflake dendritic spangle of galvanized zinc; it has a smooth reflective surface with faint hexagonal boundaries (figure 2).

Galfan is not a new coating, it was first developed around 1980 at the Centre de Recherche's Metallurgies (CRM) in Belgium under the sponsorship of The International Lead Zinc Research Organization (ILZRO), and the first industrial trial of Galfan was run at Ziegler in Mouzon (France) in 1981.

The original development aim of Galfan was to improve the corrosion resistance of Galvanize while keeping its key features of: good sacrificial protection by Zinc, good formablity, weldability and good paintability in coil coating.

CRM's development outcome was a coating with improved corrosion resistance, sacrificial protection, formability and paintability, thus exceeding ILZRO's original project aims.

Why now, Galfan is not a new coating, it has been widely adopted and incorporated in many international standards including EN 10327, EN 10214, ISO 14788, JIS G 3118, JIS G 3317 JIS and ASTM A 875/A 875M & A 755/A 755M. 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 extra cost associated with using re-alloyed ingots. Galfan was promoted by manufacturers as a premium product and sold at a premium price. In addition, most Galfan was being made on dual pot lines, and the associated extra cost of running 2 pots was typically loaded onto the Galfan cost structure. Manufacturers at that time were not making low coating mass Galfan

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& most consumers at that time were not happy to pay a premium for a better product, except for those 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.

Galfan production continues in Europe at several Arcelor Mittal facilities in both Belgium and France, at TKS in Germany, Rautaruukki Finland and at Tata Steel in North Wales, as well as in the US, and several Asian countries. This contrasts to Galvalume production, where now in Europe only Arbed in Luxembourg (Arcelor Mittal) produces Galvalume.

Outside of Europe, and over time, the original benefits of Galfan have largely been forgotten. Since its original introduction the market has changed, the market for painted coil has grown, and an increasing number of steel companies are now buying the pre-alloyed CG alloy (Zn-Al) for use on GI lines. Furthermore, the 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. In some markets, there has also been a trend towards thinner steel gauges. For a given coating weight the coating cost per tonne of steel increases with decreasing steel gauge, thus putting further pressure on coating costs.

Times have changed, and the unique corrosion and paintability benefits, low cost, and the relative ease of production make Galfan a perfect choice for today's market.

Criteria for Selecting a Metallic Coating

Steel sheet is galvanized to provide corrosion resistance to the underlying steel substrate. In selecting a metallic coating it is important to understand how zinc protects steel from corrosion and how alloying zinc with other elements alters the corrosion resistance of the coating as well as other key product attributes.

Zinc coatings protect steel by providing both a physical barrier to the underlying steel and by providing galvanic protection, that is, acting as a sacrificial anode to any bare spots, such as cut ends and small holes in the coating.

Barrier Corrosion Resistance

It is well known that alloying zinc with aluminium increases the corrosion resistance of the zinc coating, but why is this so? The answer lies in the properties of the thin film of corrosion products that form on the metallic surface.

The corrosion rate of zinc aluminium coatings decrease over time as the corroding surface becomes enriched in more stable aluminium containing corrosion products. The thin film of corrosion

products formed on Galfan are finer, more stable and more tightly adhered to the surface than those formed on zinc (figure 3). This gives Galfan at least twice the corrosion resistance of regular galvanized coatings. 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 figure 4. 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.

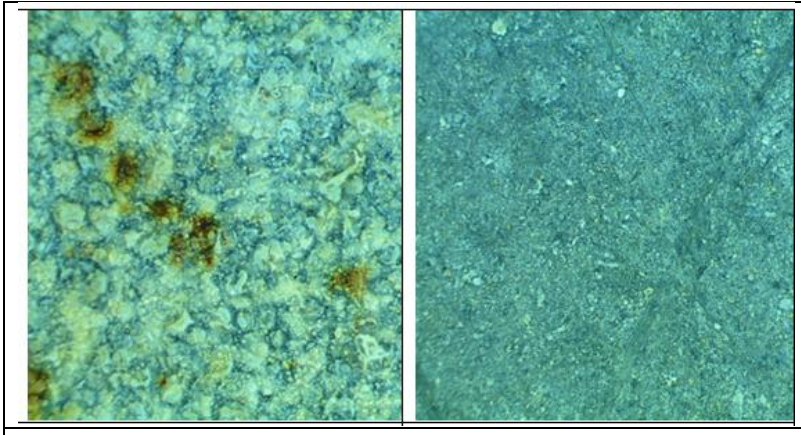

Figure 3. The film of corrosion products formed on Galfan in a marine environment (Right) is more stable than the film formed on regular Galvanize (Left). The Galfan film becomes enriched with aluminium over time thus slowing the corrosion rate.

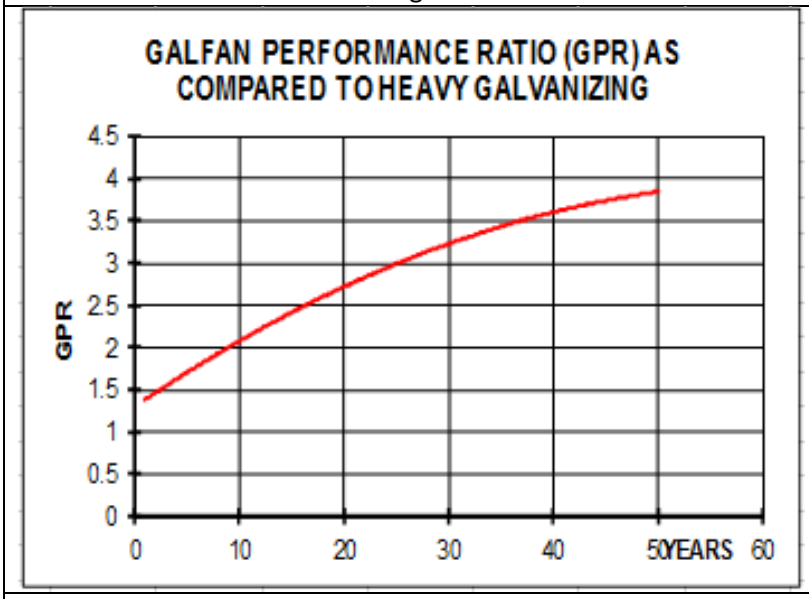

Figure 4. The Galfan Performance Ratio (GPR) shows Galfan becoming more effective over time than regular galvanizing.

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Galvanic Protection

Galvanic Protection, otherwise known as Cut-edge, Sacrificial or Cathodic Protection is the ability of the metallic coating to protect the bare steel on cut-edges and around breaks in the coating. For zinc aluminium coatings, the galvanic protection offered by the coating is largely dependent on the amount of zinc present in the coating. Corrosion is an electrochemical process requiring both anodic (oxidation) and cathodic (reduction) reactions to proceed. An actively corroding section of steel will be anodic, and by coupling this steel with zinc it becomes cathodic, driving the corrosion reaction in the reverse direction. By forcing the zinc corrosion rate to increase the steel corrosion rate is decreased. Although also anodic to steel, aluminium doesn't offer the same protection as zinc, because the anodic reaction tends to form very stable corrosion products that passivate the surface of the aluminium, thus stopping the aluminium oxidation reaction from proceeding and protecting the steel substrate.

It is the high Aluminium content of Galvalume that gives it its good barrier protection, but also gives it its poor cut-edge protection, compared to regular Galvanize.

But what about Galfan, it also contains Aluminium? Galfan contains much higher zinc content than Galvalume (95% compared to 43.5% for Galvalume). Initially, a pure zinc coating will provide a slightly higher corrosion current than Galfan, however Galfan will continue providing galvanic protection over a much longer period of time as the zinc coating becomes depleted at a faster rate than the Galfan coating. And in long-term exposure tests, Galfan demonstrates improved cut-edge protection over Zn (figure 5).

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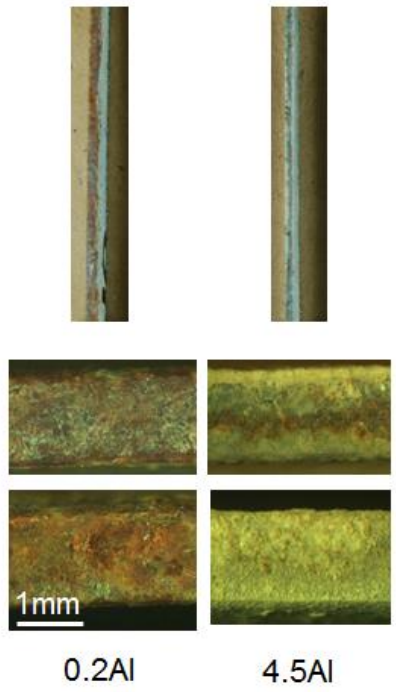	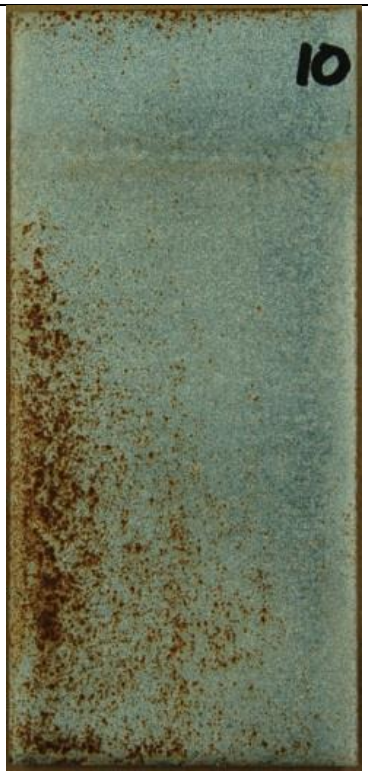	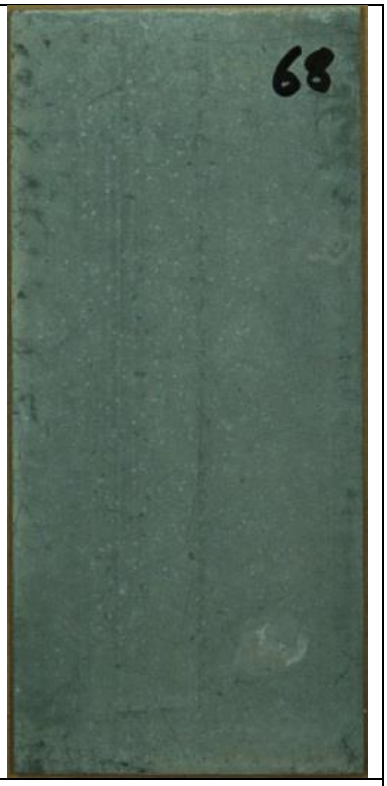
Top View of Cut-Edge, 1.6mm HRC, Galvanize (left), Galfan (right)	Galvanize coating after 5 years exposure at a severe marine site.	Galfan coating after 5 years exposure at a severe marine site.

Figure 5. 5 Year Corrosion Exposure Test at Belmont Beach, with Teck, Galvatech 2015.

Galfan versus Zinc or GI

The level of atmospheric corrosion resistance required from any coating will depend on the environment in which the product will be used (location) and the durability requirement for that product (how long is it expected to last). And for any coating class, the atmospheric corrosion resistance and therefore the durability of the coating is related to its thickness. However regardless of the environment in which it is used or the durability requirement of the product, Galfan gives the steel purchaser the opportunity to half the coating mass, compared to regular galvanize while still meeting the product requirements. Alternatively, the same coating weight can be maintained, and corrosion protection doubled, in order to achieve a premium product.

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Galfan - Paint Adhesion

Coil paint coatings are applied for aesthetic reasons and to further enhance the corrosion resistance of the coil. In general, the paint coating improves the barrier corrosion protection of the duplex (zinc + paint) coating system, while the underlying metallic coating provides galvanic protection for cut-edges, contact with fasteners and in cases where the paint coating is damaged.

So for Duplex systems there is a strong requirement for the underlying metallic coating to offer good galvanic protection.

The adhesion of the paint coating to the metallic coating has a significant impact on the appearance and durability of the coating. Poor paint adhesion can result in dis-bonding of the coating. A flaking coating also provides local conditions where accelerated corrosion may occur. So for a duplex coating system there is a strong requirement for the paint coating to be very well bonded to the metallic coating.

Painted galvanized coil is often formed into a variety of shapes. In these situations the ductility of the coating becomes important as micro-cracking, or in worse cases flaking, of the metallic coating affects both the adhesion and corrosion resistance of the coating. So for a duplex coating system to undergo secondary forming operations there is a strong requirement for the metallic coating to be ductile.

Paint adhesion on Galfan has been tested extensively in Europe, North America & Japan, and Galfan is accepted within the industry as having the best paint adhesion of all of the zinc aluminium alloy coatings. The reason for the good paint adhesion of Galfan is two-fold:

1. Uniform crystal orientation favours good paint adhesion, and skin passed Galfan has the best, i.e. most uniform crystal orientation of all the zinc aluminium coatings;
2. Galfan is also the most ductile of all the zinc aluminium coatings. This property results in Galfan having reduced micro-cracking on bends and allows it to be bent into sharper profiles than other coatings without damaging the coating.

The good galvanic protection offered by Galfan also allows it to resist edge creep at cut-edges, and red staining at fasteners.

Alternate Coating Chemistries

The most common zinc coating in use worldwide is regular Galvanize, and overtime there have been several technological developments designed to improve its performance, particularly its corrosion resistance. Some of these innovations, such as Galfan and Galvalume, involve alloying zinc with aluminium, while others involve alloying zinc with magnesium and aluminium. Each of these different metallic coating types have their own unique physical and chemical properties, which are

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strongly related to the coating microstructure. Achieving the correct microstructure can depend on several variables including the coating thickness, coating cooling rate and coating chemistry. And, in some case, modifying a coatings chemistry to improve one product attribute, such as corrosion resistance, can have an unintended effect on other coating attributes, such as coating ductility and paint adhesion.

Following is a brief discussion, in the context of LCM painted applications, of some common alternatives to regular Galvanize coatings.

Galvalume

Galvalume provides excellent barrier protection against atmospheric corrosion, and its good performance is dependent on the labyrinth of zinc and aluminium rich areas formed within the microstructure. Galvalume requires a minimum coating weight of 153 g/m^2 (both sides), AZ50, in order to develop its characteristic microstructure.

At low coating weights the correct coating microstructure for good barrier corrosion resistance is not developed and Galvalume suffers a step change decrease in performance. At 107 g/m^2 (both sides), or less, i.e. AZ35, Galvalume develops a “Bamboo” microstructure with greatly decreased corrosion resistance. For example, an AZ35 coating is 1/3 the thickness of an AZ100 coating, but has 1/10 the corrosion resistance, depending on the environment.

Generally, Galvalume is a good choice for bare applications when used at the recommended coating mass of AZ50 or higher and used within the following guidelines:

- Not suitable for high pH conditions, e.g. contact with concrete or for use in intensive animal farming;
- Avoid contact with dissimilar metals;
- Sensitive to sharp bends due to poor coating ductility
- Avoid water pooling.

Table 1 shows a comparison of the coating product attributes of Galvanize, Galfan and Galvalume.

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Magnesium Containing Chemistries

Adding magnesium to a Zinc Aluminium bath significantly increases the corrosion resistance of the coating, thus making magnesium containing coatings good for applications requiring very high levels of corrosion resistance, such as a replacement for batch HDG coatings. Adding magnesium to the coating chemistry also overcomes the poor cut-edge protection of high aluminium coatings such as Galvalume.

From a product attribute perspective, adding magnesium to a Zinc Aluminium bath significantly reduces the ductility/cracking resistance of the coating due to the formation of brittle magnesium zinc phases. Micro-cracking on bending may not be a big issue for the corrosion resistance of these coatings as, to a certain extent, magnesium containing corrosion products form within the cracks, and on the cut-edges, providing barrier corrosion protection. However, these coatings can be problematic to paint, especially for non-Cr $^{6+}$ treatments, micro-cracking of the coating is not beneficial to paint adhesion and these coatings can also cause delayed adhesion issues without the appropriate pre-treatment. From a process perspective, MgO formation can cause issues with bath management, dross make and coating control.

Table 1. Coating Attribute Comparison

Coating Attributes	Regular Hot-Dip Galvanize	Galfan (GF)	Galvalume (GL)
Composition (%) **Zinc** **Aluminium** **Silicon** **Mischmetal**	 99.8 0.2 0 0	 95 5 0 0.05	 43.5 55 1.4 0
Formability	4	5	3
Corrosion Resistance (unpainted flat panel)	3	4	5
Sacrificial Protection of Bare Ends and Scratches	5	5	2
Corrosion Resistance (unpainted, formed)	3	5	3
Paint Adhesion	4	5	4
Corrosion Resistance (painted, formed)	4	5	4
Weldability	3	3	2
Heat Resistance/Reflectivity	3	3	4
Coating Weight/Face (g/m^2) Dependent on reference strip and line specification	33-300	30-215	75-105 Corrosion resistant microstructure is not maintained at lower CM

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Process Comparison

In today's market the steel purchaser continues to be strongly focussed on the cost of the coated steel product, and unless he has special requirements, may not be prepared to pay a premium price for a premium product. And so to be competitive, the coated steel manufacturer must also focus strongly on his costs, including the capital and variable costs associated with producing the coated steel product. Furthermore, the steel manufacturer needs to consider the future, with continuing pressure from rising energy costs and tightening environmental requirements a certainty.

Bath Temperature

The melting temperature of Galfan (figure 6) is around 380 °C, compared to 420 °C for Galvanize and around 580 °C for Galvalume. This equates to a lower energy consumption for Galfan compared to producing regular galvanizing and a significantly lower energy consumption compared to Galvalume.

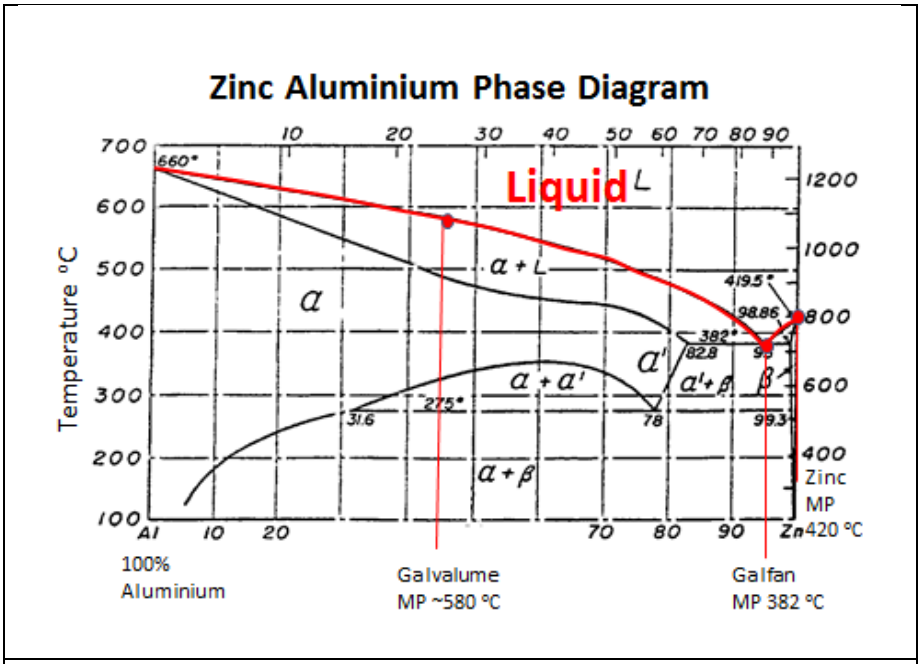

Figure 6. Zinc aluminium phase diagram showing the melting points of some common zinc aluminium alloys.

In addition to reduced energy consumption, the lower melting point of Galfan has additional process and product advantages:

1. The jet cooling and holding sections of the NOF furnace are reduced in size compared to Galvalume;
2. Fast cooling is required for Galvalume to produce the correct coating microstructure and for the top roll temperature:
    a. Galvalume requires an air cooler after the pot;

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   b. Galfan uses the same cooling system as Galvanize
3. Over-aging temperature, at 440 ^{o}C for Galfan, is much better from a metallurgical standpoint than Galvalume:
   a. Galvalume coated steel is always harder;
   b. Easier to produce soft properties with Galfan compared to Galvalume

Pot Comparison

Galfan can be produced using either a 316L Stainless Steel pot or via a ceramic pot. In a ceramic pot, where Galvalume may suffer from pot inductor corrosion, Galfan does not, due to its lower operating temperature. The lower bath temperature of Galfan also lowers the pot inductor requirements from 3 or 4 to only 2.

The Corrosion of Pot Hardware in Galfan is very low, because the dissolution rate of 316L in zinc is very low at 5% Al concentration, and is also favourably assisted by the relatively low bath temperature. In fact the corrosion rate of 316L in a Galfan bath is lower than in a Galvanize bath and much lower than a Galvalume bath.

Low corrosion rates allow pot hardware to stay in a Galfan bath for 4-6 weeks; compared to Galvalume, where the hardware can typically only stay in the pot for 10-15 days, or Galvanize, where the hardware can typically stay in the pot for 10 to 21 days. Galfan bath chemistry is also less aggressive to steel, so during line stops, Galfan has a low strip corrosion rate.

Aluminium is added to regular galvanizing baths to control the growth of the intermetallic layer and Silicon is added to a Galvalume bath for the same reason. Systematic pot analysis is required for these coatings in order to have good control of bath chemistry. Poor bath chemistry management will result in increased dross make, increased pot hardware corrosion and product quality issues.

For Galfan the bath Al content is not as critical, and the same coating properties can be achieved over a relatively broad range. This allows the use of pre-alloyed ingots, and no pre-melt pot is required for Galfan.

Galfan also has very low iron solubility, thus creating less dross than regular galvanize and no bottom dross. And unlike Galvalume, no dross build-up occurs on the sink roll and therefore no roll scraper is required. A process comparison for Galvanize, Galfan and Galvalume production is shown in Table 2.

Table 2. Process Comparison	Galvanize	Galfan	Galvalume
Pot Type	316L, or Ceramic, 2 inductors	316L, or Ceramic, 2 inductors	Ceramic only, 3 or 4 inductors
Melting Temperature (°C)	420 (low energy consumption)	380 (lowest energy consumption)	560 (high energy consumption)
Pot Hardware Corrosion	Medium (hardware can stay in the pot for 10-21 days)	Low (hardware can stay in the pot for 4-6 weeks)	High (hardware can stay in the pot for 10 to 15 days)
Pot Inductor Corrosion	No	No	Yes
Sink Roll Scraper	No	No dross build-up, scraper not required	Dross build-up, scraper required
Dross	Bottom and/or top dross	Less dross than galvanize and no bottom dross due to low iron solubility	Generally top dross, bottom dross with poor bath control
After Pot Cooling		Same as for Galvanize	Air cooler after pot required
Pre-melt Pot	Not required	Not required – pre-alloyed ingots are used	Required
Systematic bath analysis	Required to control aluminium	Not required, bath Al not critical over a wide range	Required to control silicon and aluminium
Over-aging in furnace	Easier to produce soft properties than for Galvalume	Easier to produce soft properties than for Galvalume	Galvalume steel is always harder
	Full hard is easier as there is no risk of soft edges	Full hard is easier as there is no risk of soft edges	
NOF	Jet cooling and holding sections of NOF furnace are reduced in size compared to Galvalume	Jet cooling and holding sections of NOF furnace are reduced in size compared to Galvalume	

Achieving Low Coating Weights

Over recent years there has been a growth in the market for painted galvanized coils. Line speeds have increased and there has been a trend for some of these manufacturers to produce low, or even minimum, coating mass products. There are however, physical limits on the actual minimum coating mass which can be achieved on any given line. Two important variables affecting the coating mass, which are independent of the coating control equipment being used, are line speed and the viscosity of the molten liquid being wiped from the strip, for example;

1. The higher the line speed, the higher the coating mass
2. The higher the liquid viscosity, the higher the coating mass

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Optimising the design of the coating control equipment and the use of strip stabilization systems can allow the manufacturer to lower coating weights but he will still be constrained by the physical limits described above, and unfortunately in some cases the LCM targets can simply not be achieved at maximum line speed.

Galfan has a 10-16% (dependent on bath temperature) lower viscosity than Zn and coating thicknesses down to 5 micron are achievable with good performance. The lower viscosity of Galfan allows for a lower coating mass to be achieved or for higher line speeds to be reached at the same coating mass, without making any other changes to the coating control equipment.

Lower viscosity also means that less wiping pressure is required in order to achieve the same coating weight, which also means that less noise and less ash is produced

Conclusion

Bronx International designs and builds coil coating lines to suit a range of different coating types, depending on individual customer requirements. Each metallic coating type has its own unique product and process attributes which determine the cost structure and the performance of the coating in its intended application.

Galfan may suit a manufacturer who is looking to lower his manufacturing costs:

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

Galfan is ideally suited to manufacturers producing painted and formed products, as it 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.

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