

Jet Vapor Deposition: The Choice for Zn Coatings of Future Steels for Automotive

Michel Boyer¹, Lionel Goiset¹, Arpad Csay¹, Nauwfel Amimi², Sergio Pace³, Eric Silberberg³

¹John Cockerill, Seraing, Belgium

²ArcelorMittal Liege, Jemeppe, Belgium

³CRM Group, Liege, Belgium

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The galvanization of steel for the automotive industry presents certain challenges that are not completely resolved by conventional technologies. The first of these challenges is the galvanization of 3rd generation Advanced High Strength Steel (AHSS) up to 290 ksi (2000 MPa). Such steels chemistries require a high alloying content to obtain the desired mechanical characteristics.

These steels may be galvanized in electrogalvanizing lines (EG), but there is a major drawback linked to the presence of hydrogen (H₂) in the electrogalvanizing process: hydrogen embrittlement. Preventing this issue requires two secondary processes which increase operational expenses (OPEX): batch annealing to degas H₂, and oiling to finalize the treatment. Another option is to galvanize the AHSS in a Hot Dip Galvanizing line (HDG).

In such cases, there are new heat cycle requirements upstream of the zinc pot: annealing temperature flexibility, higher soaking temperature, high cooling rate, flexible overaging, etc. However, one major complexity in the steel coatability in the zinc pot is the presence of non-wettable oxides of alloying elements present in AHSS such as MnO, MnSiO₃, SiO₂ leading to an uncoated surface or bare spots.

A common solution is selective oxidation to trap the non-wettable oxides in the FeO phase. All HDG furnaces for 3rd generation AHSS use selective oxidation, which requires accurate control of the following key parameters: O₂ rate, strip temperature, and O₂ and strip temperature homogeneity across the strip width. It is therefore difficult to control this process. In practice, hot dip galvanizing of strips above 220 ksi (1500 MPa) is not regularly economically viable due to the increased CAPEX & OPEX.

The second challenge is to produce exposed panels with the most advanced characteristics in terms of surface aspect, weldability, formability, coating uniformity, and corrosion resistance, together with a minimized OPEX.

Since 2016, ArcelorMittal Group is the first steelmaker to industrialize a vacuum deposition technology called "Jet Vapor Deposition (JVD)", for the continuous deposition of zinc coatings on steel coils. Compared to conventional deposition processes such as EG and HDG, this technology offers the benefits of various steel coating configurations, be it single-sided or double-sided coverage with different thicknesses of zinc on each side, along with high levels of productivity and a very good coating yield.

The technology enables the coating of steel grades with very high mechanical resistance properties (AHSS), without the major constraints of conventional processes. First of all, the JVD technology doesn't cause hydrogen absorption and embrittlement in steel, which is the major drawback of the EG process for AHSS as explained above. Secondly, this technology overcomes the problem of zinc wettability, and so also resolves the coatability issues encountered on some AHSS coated with the HDG process as previously described. After 6 years of continuous production as of the end of 2023, this industrial process has produced over 1,000,000 metric tons of coated steel coil.

JVD technology is a high-speed process and can exceed 700 ft/min (approx. 210 m/min), the present limit of conventional EG & HDG lines. We will present these developments and the commercialization of this technology to others steel makers via John Cockerill through a worldwide licensing agreement.

INTRODUCTION

This paper will present the JVD, a breakthrough technology which uses the deposition of zinc in a vapor state under vacuum. Therefore, one of the JVD innovations is achieving the smallest particle size of metal during coating. If we draw a parallel to different painting technologies, Hot Dip Galvanizing (HDG) can be compared to brush painting, electro-galvanization (EG) would be roller painting, and Jet Vapor Deposition (JVD) would be spray painting.

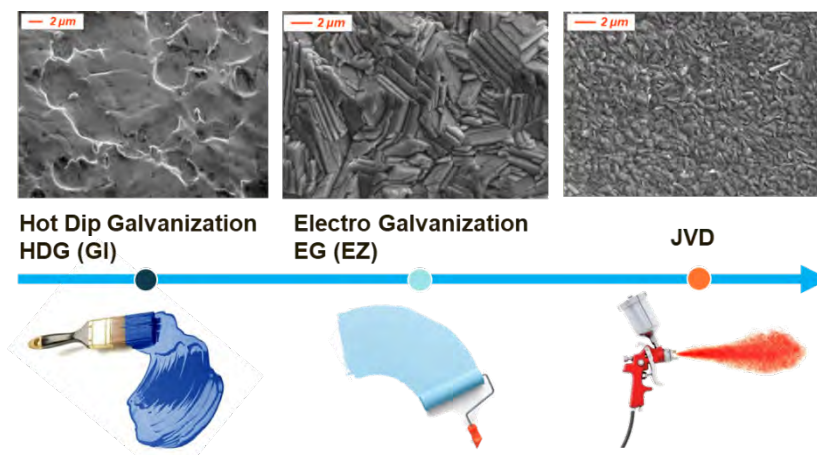


Fig. 1 Analogy between coating technologies and painting technologies

The process

The zinc ingots are melted in a classical furnace and thanks to the vacuum process - barometric effect for zinc - the evaporators are filled through piping systems. Within these evaporators, zinc is converted to vapor and is sprayed on the strip through ejectors on each side. The capacity of zinc evaporation is 1.2 metric ton per hour for both sides.

The regulating valve on each side controls the coating weight: low-weight coatings and different coating thicknesses per side are possible with a high degree of flexibility.

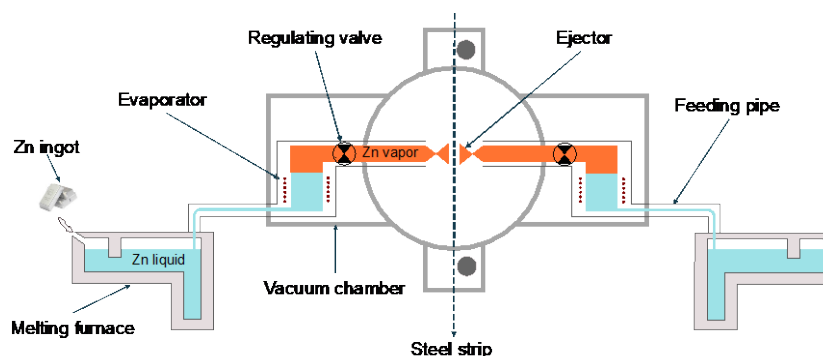


Fig. 2 Principle of process (PO WO2012/095489 patent)

Thanks to this barometric effect, there is no need for mechanical pumps to feed fresh zinc inside the vacuum chambers during production. (US 2011/000431 A1 patent)

In case of vacuum failure, the zinc will drain itself to the melting furnace, which is a key point for safety.

The zinc vapor is generated and sprayed at sonic speeds, which allows for significantly higher line speeds, higher productivity, and reduces global energy consumption. Furthermore, the JVD coating process produces outstanding zinc yield and doesn't require heating the strip to the molten zinc temperature.

Environmental impact

Different coating technologies can be compared via an environmental indicator which considers the energy consumption to produce 1 metric ton of the final coated product.

If we take hot dip galvanization as a reference with an environmental indicator value of 100%, electrolytic galvanization would reach an environmental indicator of 180%, with the JVD coming in at 90% (this value is dependant on the product mix: the percentage of cold rolled and hot rolled products).

Surface quality

JVD products have a very homogeneous surface aspect and a thin surface structure; this gives the opportunity to reduce primer thickness in some organic coating applications.

In addition, the surface after JVD coating is perfectly uniform. The roughness after coating is nearly identical to the roughness of the strip. JVD therefore produces naturally exposed steel without the costly counter-measures required for HDG.

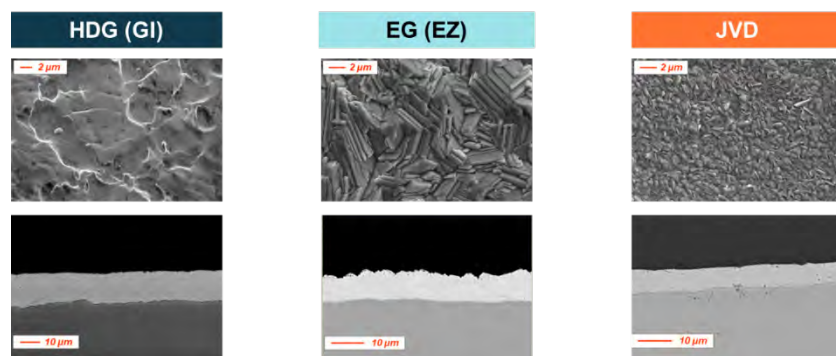


Fig. 3 Comparative surface quality between HDG, EG & JVD

Welding properties

JVD products have been compared to EG products for spot welding. Thanks to the fact that JVD produced zinc leads to less powdering and sticks less to the tools, it has been observed that the electrodes lifetime is increased by 25%.

	EG (EZ)	JVD
Strip thickness (mm)	0.68	0.72
Welding current (kA)	8.9	7.9
Electrode life (spots)	1 600	2 000



Fig. 4 Comparative electrode lifetime between EG & JVD coated products for 0.03 in strip thickness

In addition, the perfect homogeneity of the coating produces an incredible optical stability of the surface allowing for repeatable and stable laser welding parameters.

Forming tools durability

During stamping, the surface of JVD coated steel experience the same, or even less, powdering loss than the equivalent HDG products. Some end-users even increase the production campaign between two standstills.

Zinc thickness optimization:

The minimum zinc coating thickness industrially produced at Kessales is 0.02 mils (0.5 µm) per side (Z8) while the maximum zinc coating is 0.38-0.47 mils (10-12 µm) per side (G50 or Z144). The ability to produce low thickness coatings is an opportunity to reduce zinc waste and to optimize the right zinc thickness for the right application.

In addition, the JVD process is extremely stable and easy to control:

- Coat on demand, independently of the side and thickness (on the same coil or for consecutive coils),
- Rapidly change strip width format through a quick rotation of the ejector,
- Deposit coatings on a width smaller than the width of the strip to offer steel strips with coatings only where necessary,
- High flexibility of coating on various grades (ex: from MS1500 to DC01).

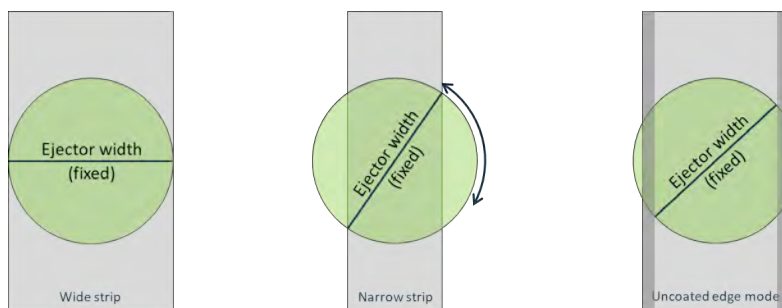


Fig. 5 Ejector positioning vs strip width (EP WO2008/107538 patent)

During production, the JVD technology allows one to change the coating thickness of the strip at anytime and nearly instantaneously.

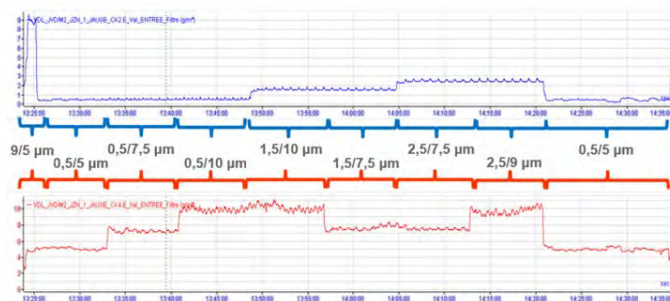


Fig. 6 Reactivity for various coating thicknesses

The JVD process allows for a constant reproducibility of the process parameters and offers a homogeneous coating profile in both the longitudinal or transversal directions.

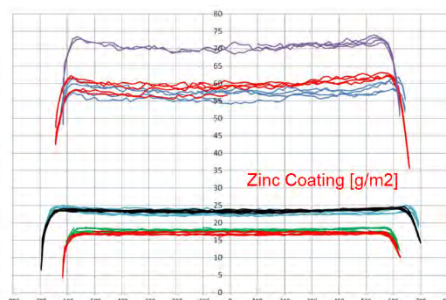


Fig. 7 Transversal coating homogeneity

The performance of the JVD process is not affected by variations of the line speed, even in the case of abrupt line speed changes such as from 400 ft/min to 100 ft/min as shown in the following figure.

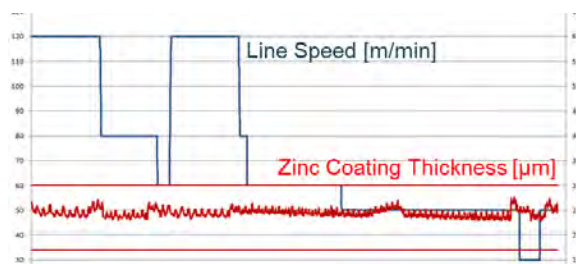


Fig. 8 Coating homogeneity in case of line speed changes

Zinc yield optimization

The zinc deposition of the JVD technology is optimized with a zinc yield of 99.5%, compared to the HDG process where the zinc yield is 92 to 94%. This increase in yield is achieved by a rotation of the ejector systems to always adapt zinc profile coating to the strip width.

The JVD coating is operating under vacuum, this process allows for:

- A pure metallic coating, without any oxides,
- The minimization of dross production. In addition, the drosses are pure zinc oxides and can be valorized as high-value products since there is no electrolyte or added chemical components as impurities.

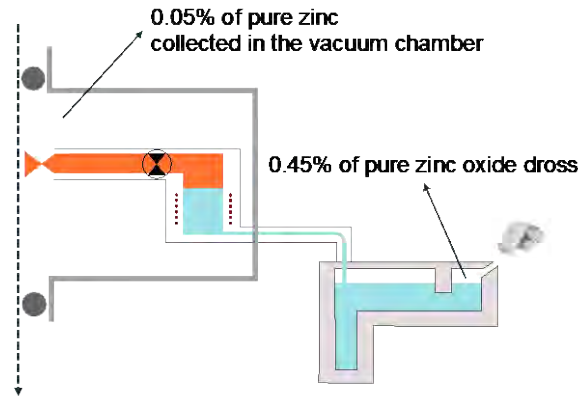


Fig. 9 zinc yield in JVD process

Speed constraints between HDG and JVD

The HDG process has a primary speed limitation of 700 ft/min (200 m/min) due to air wiping constraints. This limit does not exist in the JVD process, where line speeds of 1,300/1,500 ft/min (400/450 mpm) are possible. The HDG process has a secondary limitation in speed due to the thermal capacity of the furnace (TV value), which is highly dependent on the strip thickness. This constraint does not exist in the JVD process. JVD is only limited by the zinc evaporation rate of zinc at a given temperature, in other words, limited by the quantity of zinc deposited on the strip.

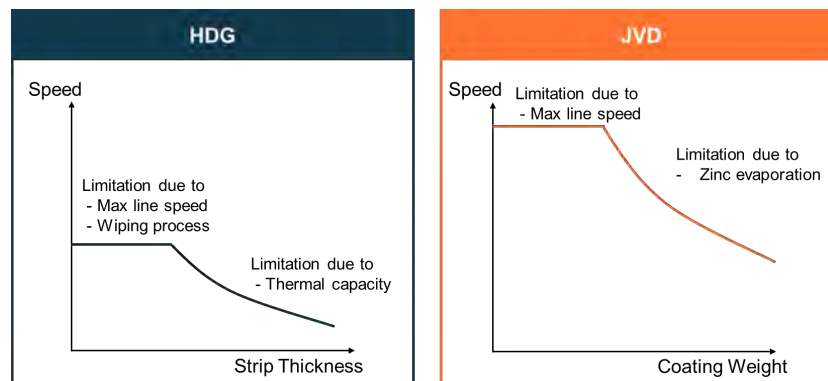


Fig. 10 Speed constraints between HDG and JVD

Process comparison between JVD and EG

JVD is often compared to electro galvanizing due to its ability to coat Advanced High Strength Steel.

The JVD process route provides a shorter lead time, requiring far less steps for AHSS, since batch annealing for hydrogen free steel is not required. The JVD process is by essence hydrogen free, a major advantage for DP 1180 to MS 1500 and above steel. Therefore, there is no risk of hydrogen embrittlement.

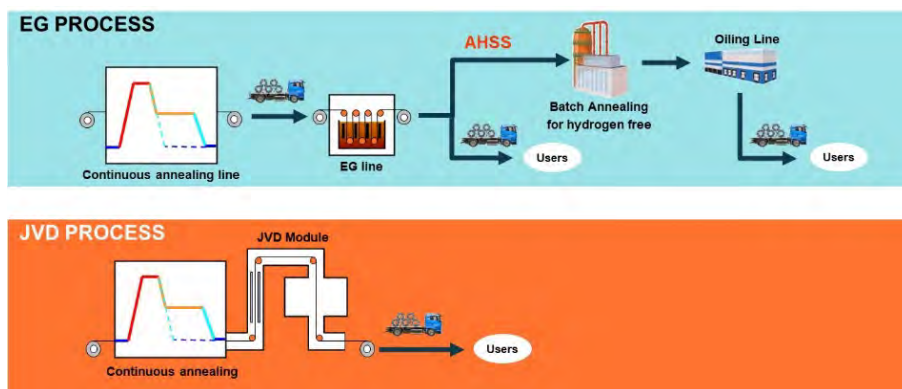


Fig. 11 JVD process route compared to EG process

Process comparison between JVD and HDG

One of the main advantages is that the JVD may be used in coupled mode (e.g., in line with annealing furnace) or un-coupled mode (e.g., stand-alone JVD).

This flexibility is a major advantage to allow for the coating of any surface from various different upstream process flows.

Some examples:

- In the HDG process, the furnaces thermal cycles are limited by strips with a large cross-section: JVD can produce at higher line speed in uncoupling mode,
- In the HDG process, high coating thicknesses are limited by the flow back of liquid zinc, JVD has the advantage of directly condensing vapor (no liquid zinc flow back behavior on strip),
- In the JVD process, hot rolled products can be coated without the requirement of pre-heating the strip up to the molten zinc temperature.

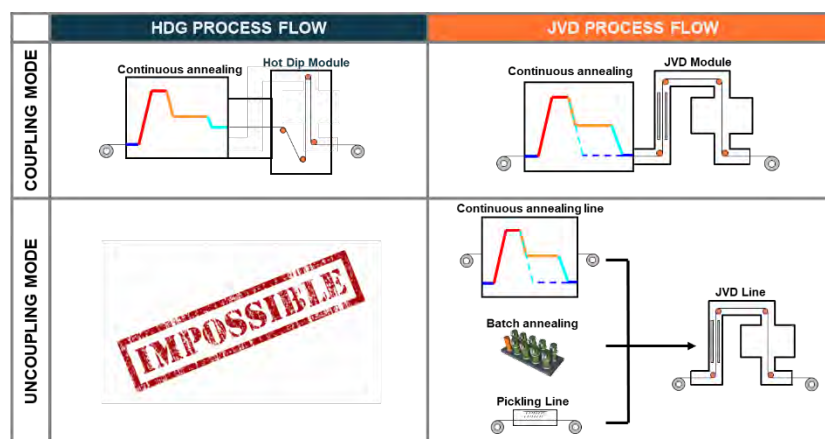


Fig. 12 JVD process routes compared to HDG- Process route

Comparative product properties

ArcelorMittal performed an internal study of the products produced by the different coating technologies.

The results were the following:

- For all the tests performed, the JVD coating demonstrated similar or better properties than the traditional coating technologies.
- The homogeneity of JVD coating is clearly superior.
- The smaller grain size of JVD products has a positive impact on corrosion resistance.

		HDG (GI)	EG (EZ)	JVD
Global aspect		+	++	++
Coating thickness homogeneity		+	++	+++
Corrosion resistance (for the same coating thickness)	SST – DIN 50021 KFW – DIN 50017	+	+	++
Temporary protection	Stack test	+	+	+
Powdering	DIN 8584-3	+	++	++
Formability	ISO 7438	++	++	++
Friction coefficient	Flat-flat internal test Dal Renault test	+	+	+
Weldability	ISO 18278-2	+	++	+++
Powder paint adhesion	EN ISO 2409 DIN 13523-5 / 13523-6	+	+	+

Fig. 13 ArcelorMittal Internal comparative product properties

A similar study has been performed by Fraunhofer Society (Europes largest application-oriented research organization). The study confirmed the results obtained by the ArcelorMittal internal comparison.

Applications of JVD products

The surface quality of JVD-coated products makes them ideal for the manufacturing of visible parts. JVD can be post-painted and offers an outstanding surface aspect. The paint layer will adhere perfectly to the smooth metallic coating, making JVD-coated coil an ideal substrate for indoor applications. Some examples:

- Interior applications (doors, desks, electrical cabinets, ...)
- Domestic appliances (washing machines, ovens, refrigerators, ...)
- Electronics (computers, laptops, casings for internal structure parts, ...)
- Construction (Air conditioner, ceiling grids, panels, metal studs, ...)
- Industry, ...

Automotive market with JVD products

JVD technology gives a unique opportunity to coat the highest strength steels one can find on the market for safety car parts. The small zinc structure enhances surface quality prior to painting, making visible or non-visible application possible.

Commercialization

John Cockerill is entitled to exclusively promote the JVD developed by ArcelorMittal to other steelmakers based on a licensing agreement.

CONCLUSION

The above paper explains how a breakthrough technology has been industrially implemented, as well as presenting the corresponding results. This industrial line is in operation in Kessales, Belgium, where over 1,000,000 metric tons of coated steel have been produced to date.

The JVD technology has the lowest carbon footprint which does not prevent it from also achieving the lowest OPEX:

- All the equipment for the JVD process is powered by electrical energy, and in the case of hot rolled galvanized steel there is no need to preheat the strip to pot temperature (heat to coat).
- The JVD thanks to its flexibility has the best steel produced yield.
- The zinc yield is a major advantage when compared to HDG

This technology must be shared to become a standard in the market. John Cockerill & ArcelorMittal are partnered in this new step forward of disseminating this technology worldwide. Promising contacts are already established in Europe (first pre-order in one of the world leader of AHSS), North America and Asia.

ACKNOWLEDGEMENTS

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