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Understanding the role of snout contamination in the formation of an oxide based defect in hot dip galvanised coating

Lewis J. Berry [a], Craig H. Phillips [b], David J. Penney [a,*]

[a] The Materials and Manufacturing Academy, College of Engineering, Swansea University, Bay Campus, Swansea SA1 8QQ, UK
[b] ZODIAC, Tata Steel Llanwern, Tata Steel Strip Products, Newport NP19 4QZ, UK

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ABSTRACT

Due to increased demand for defect free, quality critical outer panel material for the automotive sector, continued focus on zinc coating quality is required. The snout area of a continuous galvanizing line is often a major source of coating issues with various surface defects arising from poorly understood and uncontrolled snout practices. This paper investigates the formation of a snout defect termed 'the arrowhead defect', named after its characteristic arrowhead shape. Defective samples have been characterised with the use of SEM/EDX and XRD and compared with contaminated sources collected from within the continuous galvanizing line snout. It is common practice to inject wet HNx into the snout in order to inhibit the production of zinc vapour. The wet HNx promotes the formation of a ZnO layer on the surface of the liquid zinc bath, preventing vaporisation and thereby reduces zinc dust contamination. The presence of ZnO, deliberately formed through the injection of wet HNx into the snout was observed within the arrowhead defect and can be identified as the root cause of this defect. Discrete contamination particles were entrained within the tail of the defect. XRD patterns of both the defect & snout contamination have been presented to discern the nature of the contamination entrained within the zinc coating. Characteristic ZnO peaks were observed at $\theta = 32°$ for both surface contamination and at increasing penetration depths within the coating in the region of the arrowhead defect. The inclusion of the arrowhead defect in Full Finish material led to an increase in the rate of corrosion 2.5× that of the corrosion rate on non-defective material, highlighting the need to produce defect free galvanized steel for both aesthetic and corrosion purposes. Whilst the injection of wet HNx as a method of suppressing the formation of zinc vapour is a long standing process for automotive Full Finish production, due to the nature of these oxide-based defects, this process is in fact a "double edged sword" in that it solves one problem but can create another. Alternative techniques to suppress zinc vapour formation should be investigated to further drive up the quality of zinc coatings for automotive applications.

1. Introduction

The increased usage of GI Full Finish galvanized coated steel sheet for exposed outer body automotive panels has led to the need for improved surface quality. The coating section (from extension chamber to the gas knives) of a continuous galvanizing line (CGL) [1] is the source of numerous defects and various processes have been introduced in order to improve surface quality. The study of defective galvanized coatings has been paramount in understanding of defect formation and in developing strategies to improve surface quality [2,3]. Due to an ever increasing need to improve surface quality of the GI Full Finish products, further comprehensive characterisation of defective zinc coatings have been undertaken [4–6] acting as a basis for quality centred process improvement. The production of zinc vapour under a reducing HNx atmosphere within the snout [7] along with the formation of intermetallic dross [8] are two of the primary origins of coating defects. Whilst the formation of intermetallic dross particles is still a major source of defective coatings, the introduction of wet HNx snout atmospheres has all but eradicated defects that originate from zinc evaporation [7]. Zinc evaporation is undesirable since gaseous zinc will condense in the snout area and contaminate the incoming steel strip. The subsequent zinc particle alloy with the steel surface, forming FeZn intermetallics that are not readily wetted by the liquid zinc [7]. The dew point, typically around −24 °C, within the snout is a result of the injection of wet HNx which promotes the formation of a barrier layer of zinc oxide on the surface of the zinc bath within the snout, as indicated in Fig. 1, suppressing zinc evaporation. The introduction of wet HNx into the snout and the subsequent decrease in zinc evaporation to very low levels have been previously described [7,9]. The relationship between the injected dew point of wet HNx and the formation of bare spots were investigated by Arnold and Kim et al. The formation of bare spots was found to be

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* Corresponding author at: College of Engineering Swansea University, Swansea SA18EN, UK.
E-mail addresses: lewis.berry@tatasteel.com, 748386@swansea.ac.uk (L.J. Berry), Craig.H.Phillips@tatasteel.com (C.H. Phillips), d.penney@swansea.ac.uk (D.J. Penney).

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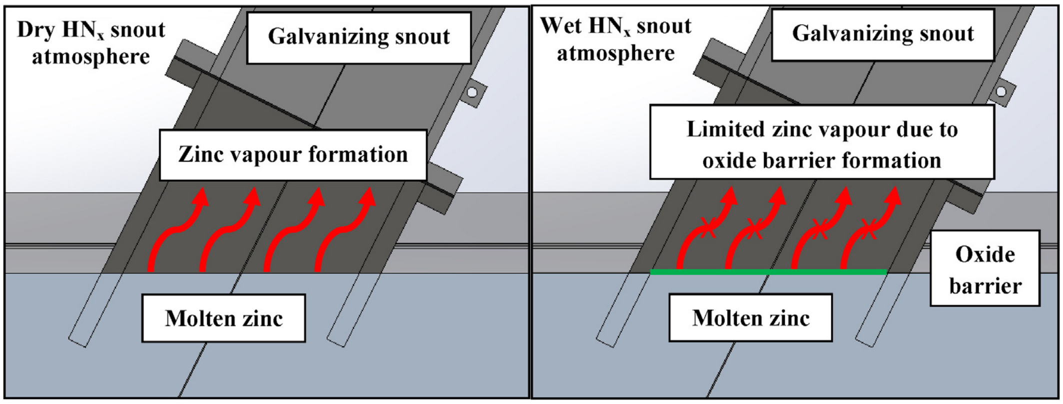

Fig. 1. Schematic of the continuous galvanizing line snout indicating the relationship between a dry & wet HNx atmosphere & the formation of Zn vapour.

due to the development of localised surface intermetallics formed through interactions between the moving steel and zinc vapour. Saint-Raymond et al. [10] defined the relationship between exposed surface area of molten zinc and the rate of formation of zinc vapour (Eq. (1)).

$$J_{Zn} = \alpha S_{evap}\left[P_{Zn}^{Sat}(T_{bath}) - P_{Zn}\right] \tag{1}$$

where

J_{Zn}	Zinc evaporation rate
S_{evap}	Evaporation surface area
T_{bath}	Bath temperature
P_{zn}	Zinc pressure
P_{Zn}^{Sat}	Zn saturation vapour pressure
α	Boundary layer diffusion constant

Upon the introduction of wet HNx, the S_{evap} term reduces to zero as does the theoretical Zn evaporation rate. However, the vaporisation of molten zinc may still be possible through breaks in the oxide barrier and needs to be further investigated in order to determine optimum snout conditions for the production of GI Full Finish. Whilst the introduction of wet HNx does act as a method of reducing zinc vapour formation, the uncontrolled formation of barrier oxides can themselves induce coating quality issues. If the zinc oxide barrier layer within the snout becomes unstable, zinc oxide particles break away and become entrained within the coating through the action of the rapidly moving steel strip, as shown in Fig. 1b. It is therefore necessary to control the size and thickness of the zinc oxide layer through the use of extraction techniques that remove the zinc and a portion of the oxide barrier layer from within the snout.

The use of pumps in the continuous removal of surface oxides formed produced through the introduction of wet HNx atmospheres was introduced by Becherer [11] and resulted in the elimination of zinc dust related defects. The Push/Pull surface cleanliness system was optimised by Phillips et al. [12] utilizing water modelling to discern optimum settings for the removal of surface contamination. However, the use of a centrifugal snout pump Push/Pull type configuration can cause turbulence within the snout leading to interactions between the strip surface and the oxide layer, and as such new on line industrial techniques have been designed to continuously remove the surface dross layer [13].

1.1. Mechanism of defect formation

The mechanism of formation of the arrowhead defect can be observed with use of the snout camera. The attraction of surface oxides to the moving strip due to liquid zinc turbulence causes oxide entrainment within the galvanized coating as observed in Fig. 2 which shows the zinc bath surface inside the snout. Surface contamination is present at the extremities of the molten zinc surface. The movement of this contamination towards the moving strip can be observed readily, leading to the entrainment of this contamination in the coating. The uncontrolled formation and entrainment of surface oxides results in the creation of the arrowhead defect as observed by the continuous galvanizing line surface quality camera system as highlighted in Fig. 3. The arrowhead defects are linked to the insufficient removal of barrier oxides from the snout surface. Achieving the correct balance between removing excess surface oxide and maintaining an inhibiting surface layer is complex. If the rate of removal drastically exceeds the rate of formation of the barrier oxide then an exposed surface of molten zinc will, increase the rate of formation of zinc vapour. This was described in detail by Arnold et al. [7].

Contamination originating from around the snout area has been previously characterised [14] with a consideration for the effects on coating quality [15], whereby the inclusion of mixed $ZnAl_{2-x}Fe_yO_4$ spinel oxide by-products into the coating resulted in the formation of outbursts of intermetallics. However, the contamination characterised were limited to oxidic, bottom and blowing dross with no consideration of by-products formed within the snout. Furthermore, no characterisation has been achieved on a microscopic scale. This paper presents an overview of

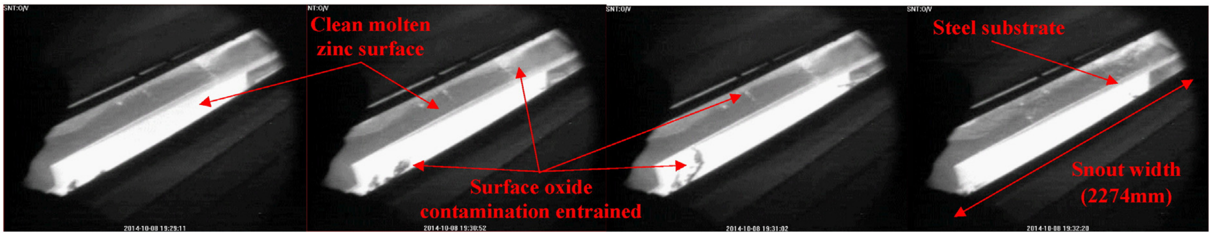

Fig. 2. Time-lapse image from snout camera highlighting the entrainment of surface oxides into the zinc coating. Central light and dark regions are uncontaminated molten zinc with surface contamination present at the extremities of the snout, which are seen to be moving towards the steel substrate resulting in entrainment of contamination into the coating.

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