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VISUALISATION OF DROSS MOVEMENT DURING GALVANIZING OF STEEL

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Abstract— **Large amount of waste material is observed near the surface of the bath in the form of Dross during the study of continuous galvanizing line. This waste material,Dross, is the by-product of the galvanizing process which consists of loose iron particles (iron salts) that have reacted with zinc in the galvanizing kettle. Dross is formed due to reaction between aluminium, iron and zinc in the zinc bath. This Dross causes defect on the coated product which results in reduced quality of the product. No efficient method, however, has been developed till date. For the development of an efficient method of removing the dross, it is important to elucidate the motions of the top and bottom dross in a real hot dip plating bath. The combined phenomena of aluminium, strip temperature and iron dissolution were simulated in order to predict and to better understand the generation and movement of inter metallic dross particles within certain regions of a typical galvanizing bath. Temperature and aluminium concentration can be correlated with the solubility limits of aluminium and iron in the zinc bath to determine the amount of precipitated aluminium in the form of Fe2Al5Znxdross. A numerical analysis was done to simulate the velocity and temperature fields in an industrial galvanizing bath for the continuous coating of steel strip.**

The information worked out in this paper is of major significance in the prediction of the formation of dross particles, which can cause defects on the coated product. Mathematical model is developed and parameters are optimized with the help of simulation technique. Also the dross formation is reduced and the process parameters are improved. The simulations allow visualization of regions of varying velocity and temperature fields and clearly illustrate the mixed and stagnant zones for different operating conditions .

Index terms- **Dross minimization, galvanizing line, Al content, Zinc bath,coating.**

I. INTRODUCTION

During the hot dip galvanizing, the steel strip enters into the bath at a temperature of 465°C. At this temperature, the mobility of iron atoms within the strip enables them to escape and enter into the zinc bath. In turn, this can lead to the formation of inter metallic within the bath known as dross particles, which can have detrimental effects upon the finished products and bath hardware. Dross can be defined as scum on molten metal with the implication that it has no value and it an undesirable material. Dross can be of two types, mainly top dross and bottom dross. Top dross is composed of suspended masses of long intermetallic spikes that are usually interwoven together in clumps. This top dross is formed at the surface of molten zinc due to reaction between iron and aluminium, it forms oxides at the surface due to its greater affinity towards iron and as it the lighter metal. This top dross is removed at regular intervals, often known as skimming. Bottom dross that is floating in the galvanizing bath, due to temperature inversions, adheres to surface of parts being galvanized. This dross becomes encapsulated in the free zinc layers during withdrawal, causing excess coating thickness and surface irregularity. The formation of floating dross results iron is rejected from the solution. Iron has a limited solubility in molten zinc. At the temperature of 465°C, iron solubility is about 0.05 %. Above this value, iron reacts with molten zinc and falls to the bottom as dross. In continuous galvanizing; aluminium in the bath plays an important role in product quality control and the economics of operation. However, maintaining the bath aluminium content at an optimum level for a specified product is a challenging task, mainly due to enrichment of aluminium in the coating. Adequate control of aluminium (Al) content in the galvanizing bath is critical to the coating quality

When the bath Al is too high, coating becomes more difficult to anneal resulting in silver edges, powdering, flakes and other defects. GA coatings are also more susceptible to streaking defects at high bath Al contents.

When the bath Al is too low, an excessive amount of bottom dross will form during GA production, leading to a prolonged upward product transition with a bath loaded with numerous floating dross particles, low bath Al also causes more severe dross build up on sink rolls and more intensive corrosion to submerged hardware. In general, GA production is rather unforgiving to bath Al fluctuations.

The situation becomes even more complicated if sheet steels consists of different grades, with some containing significant amount of P and other alloying elements. To achieve excellent product quality, the bath Al content should change to accommodate the changes in steel grades. This can be an impossible task as bath assays are taken once every few hours to analyse the assays. Product transition from galvanizing to GA by converting the galvanizing bath can be very challenging. Predicting the exact duration of this long process based on experience may be inaccurate as the duration is affected by many operational conditions such as coating weight, line speed, strip width and temperature. If the bath Al decreases faster than anticipated, some GI products will be produced at low bath Al content, resulting in formability problems and coating defects due to incomplete inhibition at the coating/substrate interface. If the bath Al decreases slower than expected, the production schedule may need to be altered because the unforgiving GA products cannot be produced when the bath Al is too high.

To minimize the dross, aluminium is added into the zinc bath to lower the iron dissolution. The iron solubility with molten zinc is reduced by aluminium addition and temperature variation of strip entering into the bath. The dross formation is highly dependent on aluminium % wt. of bath, iron dissolution and strip entry temperature. The dross minimization is done using these three parameters using the theory of heterogeneous nucleation and the objective function is formed using this theory. And the minimization of dross is done by optimizing these parameters using simulation.

A. Mechanism of formation of Dross:

Byproduct of the galvanizing process which consists of loose iron particles (iron salts) that have reacted with zinc in the galvanizing kettle. Dross can contain more than 94% zinc (6% iron).During galvanizing, some Fe is constantly transferring into the molten Zn Molten zinc can only dissolve a small amount of Fe (about 0.04% maximum). As more Fe transfers into the molten zinc, the "surplus" Fe combines with zinc to form very tiny dross particles. The reaction is **Fe + 13 Zn = Fe Zn$_{13}$**

II. METHODOLOGY

A. MATERIALS USED:

Acryclic sheet, Polystryne Balls, Salt (NaCl), Optical Sensor.

Fundamental fluid flow phenomena in a real hot dip plating bath and the effects of the strip velocity on the dynamic behaviour of the two types of dross was done using one-tenth scale cold model.Some typical streak lines of model particles for the two types of dross were nearly the same as the main stream lines in the bath. The model particles were enriched in the region enclosed with the belt. This was confirmed by measurements using a newly developed particle detection sensor. The number of particles crossing a measurement position for one second, fp, called particle frequency, and the fraction of residence time of the particles at the measurement position to total measurement time, α_p, called particle holdup, were highest in the region enclosed with the belt. These quantities increased with an increase in the belt velocity.

The main objectives of this study are to reveal the size effects on the dynamic behaviour of top and bottom dross in a real hot dip plating bath. Model experiments were carried out using a one-tenth scale cold model. Models for the plating bath, top dross, bottom dross, and plating melt were determined based on the Reynolds number similitude and the Froude number similitude.The top and bottom dross were assumed to be spherical in shape and three different diameters were chosen as representative diameters for each type of dross.

B. Experiment

Concept of model design:

Although details of two dynamic similarity laws used formodel design important aspects of them are reproduced here for a better understanding of the flow field considered. The dynamic similitude for the fluid flow phenomena between a real hot dip plating bath and its cold model bath is given by thefollowing Reynolds number

$$Re = \rho_L L v_s / \mu_L \quad \text{-----------------------------------(1)}$$

Where,ρ_L is the density of the plating melt, L is the characteristic length, Vs is the strip velocity, $\mu_L$is the viscosity of the plating melt. The sink roll diameter was chosen as the characteristic length, L. The Reynolds number in the model was decided to be the order of magnitude of 10^5as the flow in the bath is turbulent. Concerning a real hot dip plating bath, the physical properties of the melt is fixed and the diameters and densities of the top and bottom dross are different. However, it shouldbe noted that in this model experiment polystyrene particles with a mean diameter, d_P, of 1.0mm and a density, ρ_p, of 1.05 *10^3 kg/m3 are used as models both for the top and bottom dross. The size and density of the model particles therefore were fixed regardless of the type of dross. NaClaqueous solutions with different densities were chosen as the models for the plating melts. The density of the NaClaqueous solution was changed depending on the type of dross. The following modified Froude number was employed to provide a dynamic similitude for the determination of the density of the model liquids.

$$Fr = \rho_L v_s^2 / (|\Delta \rho| d_p g) \quad \text{--------- (2)}$$

Where $\Delta \rho \ (= \rho_p - \rho_L)$ is the density difference between the dross and the plating melt, g is the acceleration due to gravity,dp is the diameter of dross, and the strip velocity, Vs, is used as the characteristic velocity. Equation (2) gives the following relation between a real process and its model.

$$\Delta \rho_M / \rho_{LM} = (\Delta \rho_R / \rho_{LR})(v_{sM} / v_{sR})^2 (d_{pR} / d_{pM}) \quad \text{------------- (3)}$$

where the subscripts M and R designate the model and real processes, respectively. Fe_2Al_5 and $FeZn_7$ were chosen asrepresentative top and bottom dross, respectively. The density of Fe_2Al_5 is 4.2 * 10^{-3} Kg/m^{3}and that of $FeZn_7$ is

7.25 *10^3 kg/m^3.The diameters of the top dross, d_{pR}, were assumed to be 40, 60 and 100 mm and those of the bottom dross were assumed to be 60,150 and 300 mm. Substitution of the diameters and densities of the top dross,bottom dross, model particles and plating melt (molten zinc)into eq. (3) gives the densities of the model working fluids. The densities of the model working fluids, ρ_{LM}, were 1.06 * 10^3, 1.07 *10^3 and 1.08* 103 kg/m^3 for the top dross of d_{pR} = 40, 60 and 100 mm, respectively.Those for the bottom dross of d_{pR}= 60, 150 and 300 mm were 1.04 * 10^3, 1.03* 10^3 and 1.02 *10^3 kg/m^3, respectively.Accordingly, 8.6%, 10.0%, and 11.5% NaCl aqueoussolutions were used for the top dross model particle measurements and 6.0%, 4.5%, and 3.0% NaCl aqueous solutions were used for the bottom dross model particle measurements.

C. Experimental apparatus

A sink roll was placed in a transparent acrylic vessel. An endless belt was driven by two driving rolls. The origin of the Cartesian coordinate system (x,y,z) was placed at one of the corners of the vessel. The flow field in the bath was divided into three regions.

The entry region, the exit region, and the region enclosed with the belt. The belt velocity, v_{sM}, was set at 1.5 m/s. Model particles of 32 g in mass were fed into the bath from the bath surface in the entry region for every measurement. This amount of model particles were chosen so that the measurements of streak lines, particle frequency and particle holdup could be carried out with sufficient accuracy.

D. Streak line measurement

A streak line is defined as the line on which lie model dross particles that at some earlier instant passed through a certain point in the bath. In other words, the resulting particle trail is called the streak line. Thestreak lines of model particles were observed using a high-speed video camera at 200 frames per second.

Measurement of local particle frequency and localparticle holdup

The particle frequency, f_p, and particle holdup, α_p, can be calculated from the following equations (see Fig. 2).

$$f_p = N/t_M(\text{Hz}) \quad \text{------------(3)}$$

$$\alpha_p = (\Sigma t_{pi}/t_M) \times 100(\%) \quad \text{------------(4)}$$

where N is the number of particles crossing the laser beam of the particle detection sensor, t_M is the total measurement time and t_{pi} is the time duration for the i-th particle to cross the beam. The distance between the light source and the detector, the sampling frequency of the output signal and the total measurement time t_M, were set at 20 mm, 5 kHz and 2 min, respectively. The accuracy of the present measurement method is given in the previous paper. It should be stressed that the measurements were carried outafter the flow in the bath became steady.

It should be noted that when both the particle frequency, f_p, and particle holdup,are high at a measurement position, many dross particles pass there slowly.

III. Results and Discussion

A. Top dross model particles in the entry and exit regions

The most definite streak line is denoted by a_T, where the subscript T designatesthe top dross model particle. The streak lines denoted by bT, c_T and d_T are also pronounced. These streak lines are similar to the main stream lines.The streak lines of top dross model particles for dpR= 40 mm and 100 mm were approximately the same.

Since the density of the top dross model particle was slightly smaller than that of the NaClaqueous solution, many top dross model particles by gathered on the two parts of the bath surface denoted A and B.

B. Bottom dross model particles in the entry and exitregions.

The main streak lines denoted by a_B, b_B, c_B, and d_B are approximately the same as the mainstream lines mentioned above, where the ubscript B designates the bottom dross model particle. As the density of the bottom dross model particle was slightly larger than that of the NaCl aqueous solution, many bottom dross model particles stayed on the bottom wall and some of them were frequently lifted up, i.e., ejected into the bulk of the bath,as indicated by the solid lines b_{B3}, b_{B4} and b_{B5}.

Bottom dross model particles were hardly observed in thecentral part of the bottom wall.

Top and bottom dross model particles in the region enclosed with belt

Top and bottom dross model particles are most likely to gather in the region enclosed with the belt. The number of dross model particles in this region increased as the belt velocity, v_{sM}, increased.

Thearrows denote the direction of flow. In addition, these streak lines were found to be hardly dependent on the diameter of the dross, d_{pR}It is interesting to note that both the top and bottom dross model particles are carried deep into the clearances between the belt and the sink roll.

We therefore investigated the motions of the dross model particles moving in the two clearances more in detail. The typical motions of top and bottom dross model particles in the two clearances were observed with a highspeed video camera in the middle plane of y = 151 mm. The time interval between successive particle images was the same. The velocity of a top dross model particle entering the clearance on the entry side decreased as it approached the bottom of the clearance. This is because the particle have to move against apressure rise or an adverse pressure gradient in the clearance.

On the other hand, the velocity of a bottom dross model particle entering the clearance on the entry side hardlydecreased because the density of the bottom dross model particles was larger than the NaClaqueous solution. The streak lines of top and bottom dross model particles on the exit side clearance were approximately the same. The velocity of a model particle entering the clearance on the exit side was considerably lower than that in the clearance on the entry side. The adhesion of the top and bottom dross model particles to the belt took place in the two clearances regardless of the dross diameter. Both the top dross particles and bottom dross particles entered into the clearance between the sink roll and the belt. The velocity of the top dross particle entering the clearance on the entry side was different from that of the bottom dross particle.

C. Contour lines of particle frequency fp and particleholdup:

Top dross model particle

Data could not be obtained in the regions designed by white color mainly due to experimentaldifficulty. The distributions of particle frequency, f_p, were approximately the same regardless of the diameter of the top dross, d_{pR}. The particle frequency, f_p, is eventually high near the belt in every figure, implying that many top dross model particles move along the streak line.In the region enclosed with the belt, the measured fp values are very high compared with those in other regions. This isbecause the model particles trapped once in this region are difficult to escape from there before a steady state is established. The experimental results of particle holdup, α_p, for d_{pR}= 60 mm in the middle plane of y =151mm. The measured α_p values are high in the lower partof the exit region, in the region enclosed with the belt, and in the left-half part of the entry region. The three sub-regions designated by F_1, F_2, and F_3 in the left part of the entry region are regarded as stagnant regions. The contour lines of particle holdup,α_p, for d_{pR}=40 and 100 mm in the middle plane of y = 151mm. and the measured p values in the whole bath were lower than those for d_{pR}=60 mm. At a glance, this result seems strange. The reason can be explained as follows: Under the present experimental conditions the relaxation time of a model particle is expressed

by

$$\tau = \rho_{LM} d_{pM} (\rho_{pM} + \rho_{LM}/2)/(18\nu_{LM})$$

-----------------------------(6)

where _LM is the kinematic viscosity of the NaCl aqueous solution. The relaxation time is a measure for the response time of a particle to a change in liquid flow velocity around it. In eq. (6),ρ_{pM} and d_{pM} are fixed, ρ_{LM} is lower for d_{pR}= 40 mm than for d_{pR}= 60 mm, and ν_{LM} is higher for d_{pR}= 40 mm than for d_{pR}= 60 mm. This fact means that the

relaxation time is shorter for d_{pR}= 40 mm than for d_{pR}= 60 mm. Accordingly, the top dross model particles for d_{pR}= 40 mm respond to a change in the liquid velocity more quickly than those for d_{pR}= 60 mm. Therefore, top dross model particles for d_{pR}=40 mm are less captured in the stagnant regions (F_1, F_2, and F_3) than those for d_{pR}= 60 mm. On the other hand, the buoyancy force acting on a top dross

model particle is expressed by

$$F_B = (\pi/6)(\rho_{LM} - \rho_{pM}) g d_{pM}^3$$

----------------------(7)

This force increases as the density difference, (ρ_{LM} _ ρ_{pM}), increases. Accordingly, particles for d_{pM}= 100 mm are more likely to be forced to move vertically upwards than those for d_{pR}= 60 mm and are not able to stay in the stagnant regions (F_1, F_2, and F_3). The spatial mean values of f_p, denoted by fpm, were calculated for the three regions in the middle plane ofy=151mm to find out the regions where the top dross model particles are enriched. The top dross model particles floating on the bath surface were excluded in the calculation. Accordingly, the top dross model particles of every diameters of dross, d_{pR}, are most likely to gather in the last region before a steady state is established. This result is consistent with the finding obtainedby flow visualization with the high-speed video camera.

Bottom dross model particle: The distributions of f_p are similar to those for the top dross model particles. The spatial distributions of $f_p$were approximately the same for all the dross diameters, d_{pR}. The magnitude of f_p, however, became low everywhere in the bath as the d_{pR} became large. The number of bottom dross model particles staying on the bottom wall increased as the d_{pR} increased, because the gravitational force acting on thebottom dross particles increased as d_{pR} increased, as suggested from eq. (7). The mechanism of the formation of these three stagnant regions cannot be clearly explained at present. However, the existence of the three stagnant regions is very important because the efficiency of dross removed is lowered.

IV. CONCLUSION

Main findings obtained in this study can be summarized as follows:

(1) The typical streak lines for the top dross model particles in a model bath were approximately the same as the main stream lines in the bath. Many top dross model particles stayed on the bath surface in the vicinity of the side walls parallel to the belt in the entry and exitregions.

(2) The typical streak lines for the bottom dross model particles were also approximately the same as the main stream lines in the bath. Many bottom dross particles stayed on the bottom wall under the sink roll and in the entry region. The number of particles staying on the bottom wall in the entry region increased and theparticles moving in the bulk of the bath decreased as the dross diameter became large.

(3) The typical streak lines for the top and bottom dross model particles in the region enclosed with the belt were approximately the same regardless of the dross diameter. These streak lines were very close to the main stream lines in this region. The model particles wereoften carried deep into the two clearances between the belt and the sink roll, and some of them were caught in the two clearances. This may be one of the main causesfor the adhesion of the dross to the strip in a real hot dipplating bath.

(4) The particle frequency, f_p, of the top dross modelparticles was hardly dependent on the dross diameter. The top dross model particles for d_{pR} = 60 mm were captured in the stagnant regions (F_1, F_2, and F_3) in theentry region. However, those for d_{pR} of 40 and 100 mmwere hardly captured in these regions.

(5) The particle frequency, f_p, of the bottom dross model particles became low as the dross diameter, d_{pR}, increased. Many bottom dross model particles for d_{pR} = 60 mm were entrapped in the stagnant regions (E_1, E_2, and E_3)in the entry region. However, the entrapment of bottom dross particles of d_{pR} =150 and 300 mm in the stagnant regions was not observed.

(6) Both the top and bottom dross model particles were most likely to gather in the region enclosed with the belt regardless of the dross diameter.

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