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The Application of the Electromagnetic Dross Removal Technology Applied in Zinc Pot of Hot-Dip Galvanizing Line

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Abstract

A specially designed experimental platform based on the principle of electromagnetic hydromechanics to remove zinc drosses formed on the surface of molten zinc in zinc pot of hot-dip galvanizing line was presented in this work. The main components of the platform were electromagnetic field generator, zinc pot, cooling water system, power control cabinet, and supporting platform. The electromagnetic field generator was installed on the top of zinc pot. Three experiments were conducted when the loading current, frequency, and the distance between the bottom of the electromagnetic field generator and the surface of molten zinc were 300 A, 20 Hz, and 180 mm, respectively. The results showed that the relative aggregation degrees of zinc drosses were 26.4, 27.1, and 25.9. It manifested that zinc drosses can be effectively aggregated by an external electromagnetic field to a desired location so as to remove from the surface of molten zinc in zinc pot.

Keywords

Electromagnetic Field, Electromagnetic Force, Flow Field, Zinc Dross

1. Introduction

The hot-dip galvanizing process is one of the most effective ways used to protect steel components. With the higher usage requirements of applications in automotive and construction industries, the better surface quality of galvanized plate is desired. As is known to all, zinc dross forming on the surface of molten zinc in zinc pot is unavoidable to form and becomes one of vital factors damaging the surface quality of galvanized plate [1]. At present, the prevalent methods for removing zinc dross mainly depend on manual or robot operation. However, the noise and high temperature working circumstance around the zinc pot are not suitable for workers doing the dross removing operation. Furthermore, the confined space limits the operation zone of robot, which still needs to cooperate with manual operation. In addition, it is likely to induce surface fluctuation of molten zinc for both manual and robot zinc dross removal operation, which may lead to serious surface quality problems [2]. To date, there is no perfect way to solve the dross removal problem encountered in galvanizing process, and a novel technology substituting manual and robot operation is urgent.

In recent years, electromagnetic field has been applied in an array of important areas, and many remarkable discoveries have been reported [3]-[5]. Based on measuring the drag force on magnetic field lines crossing melt flow, A. Thess *et al.* put forward the noncontact Lorentz Force Velocimetry (LFV) technique, which was suited for flow measurement in high-temperature melts like steel, aluminum [6]. Xiangmeng Meng *et al.* proposed a combination of experimental investigation and multi-physical modelling to study the influence of the orientation of an oscillating magnetic field on the metal mixing in the electromagnetic stirring enhanced wire feed laser beam welding. The filler metal was distributed homogenously in the final weld under a magnetic field of 10˚ angle [7]. Lin Wang *et al.* proposed a novel and low-cost EMF-assisted MIG welding brazing method. They found that the arc and droplet can swing along the weld width direction under the effect of additional electromagnetic force to improve the wetting of molten aluminum on the steel surface [8]. Zhipeng Ma *et al.* presented a method for electromagnetic ultrasonic-assisted brazing, the results indicated that electromagnetic ultrasonic-assisted brazing prevented substrate cracking from ultrasonic vibration, and the parameters and processes were easy to control, which protects the experimental materials [9].

From all the research above, it can be deduced that electromagnetic field has a remarkable effect on the spreading or flowing of molten metals. Up to now, there have been few investigations focused on dross removal technology by utilizing electromagnetic field. In our previous work, the authors carried out a systematic study on the effect of electromagnetic field on flow field of molten zinc and the distribution of zinc drosses in zinc pot of hot-dip galvanizing line [10]. The results illustrated that the feasibility of the electromagnetic dross removal technology from a theoretical standpoint. On this condition, this work was carried out in the light of the former studies, and the main objective of this work was devoted to developing an apparatus serving as to remove zinc dross formed on the surface of molten zinc in zinc pot under the influence of an electromagnetic field.

2. Experiment

A schematic of the device designed to remove zinc dross in zinc pot of hot-dip galvanizing line is shown in **Figure 1**. The zinc pot containing molten zinc was placed on an insulated platform. The main body of the electromagnetic field generator (DJXR-800, Hebei golden century electric Co., Ltd., China) was located on the top of the zinc pot. The electromagnetic field generator was supported by a supporting platform, which was equipped with idler wheels and height regulating device. The operated zone of electromagnetic field can be changed by moving the location of the idler wheels. The distance between the surface of molten zinc and the electromagnetic field generator can be regulated by the height regulating device. The power control cabinet provided and regulated all the power used in experiments. Electric wires connected the electromagnetic field generator and the power control cabinet. The electromagnetic field was generated by three-phase alternating current and the maximum on-load voltage, loading current and frequency were 400 V, 600 A, and 50 Hz, respectively. The electromagnetic field generator was able to work in high temperature environment from 400 to 700˚C on account of it was equipped with water-cooling and protection system. Cooling water kept circular flow driven by a circulating water pump from the cooling water tank to the electromagnetic field generator though water pipes. Cooling water was used to prevent the heat transfer from zinc pot to electromagnetic field generator so as to keep the normal work temperature of the electromagnetic field generator below 80˚C. The thermocouple II was used to monitor the temperature change of cooling water.

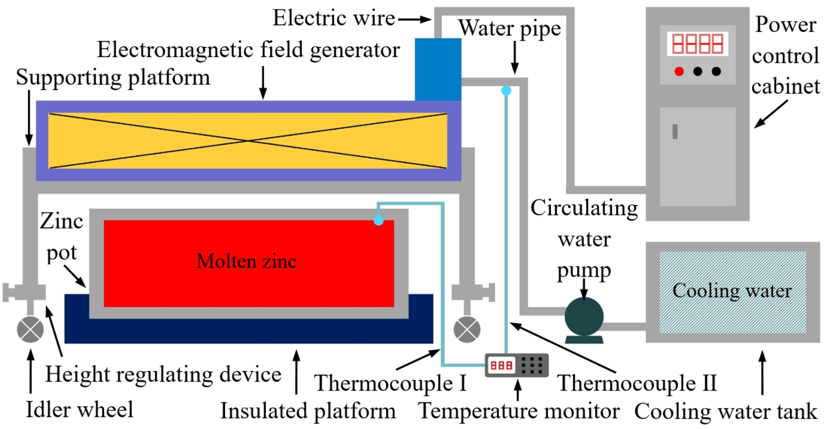

Figure 1. Schematic diagrams of the overall setup designed to remove zinc dross by the electromagnetic dross removal technology.

A photograph of the experimental setup is exhibited in **Figure 2**. All the components in this apparatus were made of non-magnetic materials including 304 stainless steel, 201 stainless steel, copper alloy, and rubber, which were not vulnerable to magnetization. Therefore, the device itself should not influence the experimental results.

Zinc ingots with a composition of 0.175% - 0.22% Al and ≤0.06%Fe were selected as experimental materials. In the experiment process, firstly, zinc ingots were put in zinc pot (made of 201 stainless steel with a dimension of 500 mm in length, 200 mm in height, and 150 mm in width) and were heated to 800˚C and experienced 30 minutes of heat preservation. Then, the zinc pot filled with molten zinc was transferred to the insulated platform. The electromagnetic field generator placed on the supporting platform was moved on the top of zinc pot and kept a 180 mm distance between the bottom of the electromagnetic field generator and the surface of molten zinc. For the convenience of observing the flowing situation of molten zinc and the distribution of zinc dross in the experiment process, a third part of the zinc pot was exposed and was not covered by the electromagnetic field generator. It should be noted that, although the size of the area on the upper surface of the zinc pot uncovered by the electromagnetic field in the experiment was designed solely for the convenience of experimental observation and operation, it is consistent with the fact that, electromagnetic field generators cannot cover the entire upper surface of the zinc pot in actual industrial production. In addition, these non-electromagnetic-field covered areas provide operational space for effectively and in real time removing the zinc dross that has been gathered by the electromagnetic dross removal technique. In the following, the power of the electromagnetic field generator was turned on and the experiment started. The loading current and frequency were 300 A and 20 Hz respectively. In the experiment process, the temperature of molten zinc was monitored by thermocouple I, and experiment was over by the time of the temperature of molten zinc below its melting point.

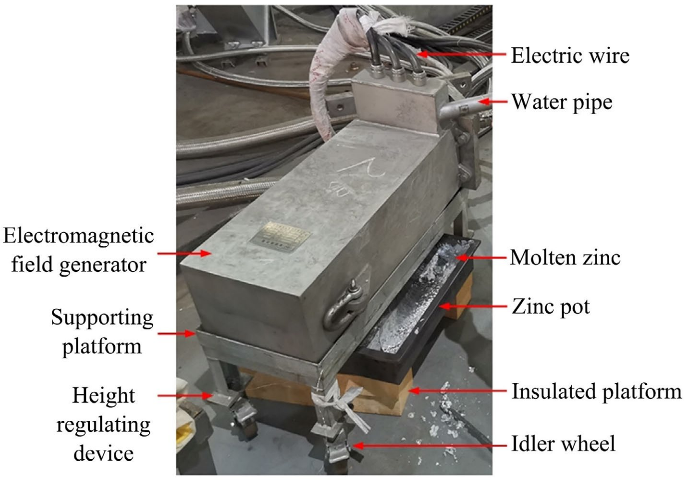

Figure 2. Photograph of the main components of the experimental setup.

3. Results and Discussion

Without the effect of electromagnetic field, zinc drosses formed and were randomly distributed on the surface of molten zinc after the zinc ingot melted as shown in **Figure 3(a)**. This phenomenon was common and consistent with the reality of the real situation in zinc pot of hot-dip galvanizing line. However, zinc drosses formed on the surface of molten zinc were regularly distributed with the effect of electromagnetic field as shown in **Figure 3(b)**. The electromagnetic field generator can produce an alternating magnetic field. The molten zinc, acting as a conductive fluid, generated induced currents within it under the influence of the alternating magnetic field. The induced currents interacted with the magnetic field to produce electromagnetic forces that drove the movement of the molten zinc. Through electromagnetic induction, energy conversion was achieved, thereby enabling the non-contact transformation of electromagnetic energy into the kinetic energy of the molten zinc. Since the electromagnetic field can be artificially controlled, meaning the electromagnetic force can also be controlled, it is possible to direct the flow of the molten zinc as desired. This allowed for the controlled directional movement of surface zinc dross by the molten zinc, achieving the goal of concentrating the zinc dross. The area labeled S_1 was covered by electromagnetic field, and the area labeled S_2 was not covered by electromagnetic field. It can be seen that there was a small amount of zinc drosses in area S_1 and most of zinc drosses aggregated at area S_2. After the experiments, the solidified zinc ingot was cut across cross-section, and the cross-section morphologies of the labeled region R_1 and R_2 were observed and the results were shown in **Figure 3(c)** and **Figure 3(d)**, respectively. It was obvious found that there were few zinc drosses on the surface of the solidified zinc ingot shown in **Figure 3(c)**, and a large quantity of zinc drosses aggregated on the surface as shown in **Figure 3(d)**. It indicated that electromagnetic field indeed effectively modified the distribution of zinc drosses formed on the surface of molten zinc.

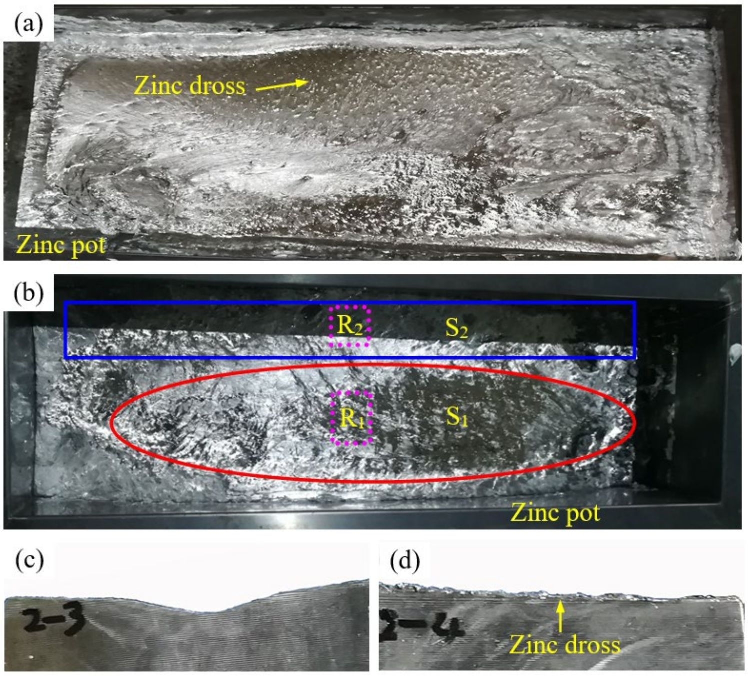

Figure 3. Morphology and distribution of zinc drosses formed on the surface of molten zinc without electromagnetic field (a) and with electromagnetic field (b). The cross-section morphology of the labeled region R1 (c) and R2 (d).

In order to reflect the aggregation effect of electromagnetic field on zinc dross formed on the surface of molten zinc, the aggregation degree was defined as the proportion of the amount of the formed zinc drosses to the distribution area of zinc drosses. For the sake of analysis, it is assumed that 100 zinc drosses were formed. Without the effect of electromagnetic field, zinc drosses randomly distributed on the surface of molten zinc, as shown in **Figure 3(a)**, and the aggregation degree under these circumstances was defined as the initial aggregation degree, D_0, which was expressed by formula (1). With electromagnetic field, zinc drosses are regularly distributed on specific areas of the surface of molten zinc as shown in **Figure 3(b)**, and the aggregation degree under these circumstances was defined as the experimental aggregation degree, D_e, which was expressed by formula (2). Thus, the relative aggregation degree, D_r, was expressed by formula (3).

$$D_0 = 100/S_0 \tag{1}$$

$$D_e = 100/S_e \tag{2}$$

$$D_r = (D_e - D_0)/D_0 \tag{3}$$

where, S_0 was the distribution area of zinc dross without electromagnetic field, m^2; S_e was the distribution area of zinc dross with electromagnetic field, m^2.

In order to verify the reliability of the results, the experiment was repeated for three times, and the results are shown in **Table 1**. It can be found that the results of the relative aggregation degrees obtained from the three experiments were similar, and the experiment was reliable. It was necessary to point out that the relative aggregation degrees were small. The main reason inducing a small relative aggregation degree was attributed to zinc drosses were not removed from the surface of molten zinc in time after flowing through the electromagnetic field working zone. Therefore, the probability of zinc drosses stayed in the electromagnetic field working zone was increased and resulted in a small relative aggregation degree. In actual industrial production, to address this problem, a dross removal zone can be set up at a specific location on the corner of the zinc pot uncovered by the electromagnetic field. Robots can be employed to perform automatic real-time operations, ensuring that the zinc dross collected by the electromagnetic dross collection device is promptly removed from the zinc pot, thereby improving the dross removal efficiency.

Table 1. The relative aggregation degree of zinc drosses.

Number of experiments	S_0/m^2	D_0	S_e/m^2	D_e	D_r
1	0.075	1333	0.0593	1686	26.4
2	0.075	1333	0.0589	1695	27.1
3	0.075	1333	0.0595	1679	25.9

4. Conclusion

An instrument devoted to removing zinc dross in zinc pot of hot-dip galvanizing line under the effect of electromagnetic field was developed. The applied electromagnetic field could drive the moving of molten zinc, and further drive the moving of zinc drosses in a designed direction. The distribution of zinc drosses on the surface of molten zinc was explored using this instrument and the obtained results were reliable. Zinc drosses were effectively aggregated in a certain zone in zinc pot on condition of applying an electromagnetic field, and the maximum value of the relative aggregation degree was 27.1. The developed instrument opened up a new way to remove zinc drosses produced on the surface of molten zinc in zinc pot of hot-dip galvanizing line. However, the current results were limited to experimental research, and there were still many aspects, such as challenges in scaling the device, managing energy consumption, ensuring material compatibility in a continuous production environment, and deserving to be considered and optimized before the real industrial application.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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