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Factors Influencing Edge Dendritic Plating of Steel Sheet in the Electro-Galvanizing Line

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Recently, the demand for Zn-Ni electrogalvanized steel sheets for home appliances and automobiles is increasing. Products should have a thick plating (30 to 40 g/m^2) on both side with a thin thickness (≤ 0.8 mm) and the highest surface quality. By a high current density operation, current is concentrated in the edge part of the steel sheet, resulting in large surface dent defects due to dendritic plating. This can lead to a low productivity due to low line speed operation. To solve this problem, this study aimed to identify factors influencing dendritic plating. A cylindrical electroplating device was manufactured. Effects of cut edge shape and thickness of steel plate, current density, temperature, flow rate, electrolyte concentration, and pH on dendrite generation of Zn-Ni electroplating were examined. To investigate effect of edge shape of the steel sheet, the steel sheet was manufactured using three processing methods: shearing, polishing after shearing, and laser. Relative effects thickness and cut edge processing methods of the steel plate, current density, temperature, flow rate, electrolyte concentration, and pH of plating solution on dendrite plating were investigated. To prevent dendrite plating, an edge mask was manufactured and its application effect was investigated.

Keywords: *Electro-galvanizing, Dendrite, Current density, Dent*

1. Introduction

The fundamental mechanism for dendrite plating growth is still unclear despite numerous studies [1-4]. It refers to the complex forms of crystal growth that are generally generated during solidification or electroplating of metals. When tiny micro-scale roughness is present on the metal surface, supply of Zn ions to the diffusion layer in the solution is facilitated. That is, a needle-shaped dendrite is generated by the concentration of current and the supply of ions at the tip of the unevenness. The dendrite plating refers to a phenomenon in which crystal growth takes place in a direction where ion supply is easy within the diffusion layer.

In general, in liquid cushion cell-horizontal (LCC-H) plating cells with excellent quality and productivity, which are horizontal electroplating methods, the steel plate becomes a cathode, and the anode uses a titanium material coated with IrO_2 [5]. In general, the anode is designed to be larger than the width of the steel plate, so current is concentrated from the anode at both edges of the steel plate, as shown in Fig. 1. As a result, both edges of the steel plate are excessively plated, or dendrite plating growth occurs. This causes various defects in mass production, and first, when the product is wound with a coil, not only causes bending on the steel plate due to over-plating of the edge area, but also causes a coil winding failure (buckling) problem. Second, the excess or dendritic plating that appears on the edge part is easily eliminated into small pieces and pressed into a roll of the subsequent process, causing a dent defect in the steel plate. As a result, there is a problem of reducing productivity due to suspension of operation or low-speed operation to remove compressed metal pieces. In addition, the dropped dent pieces float in the plating solution and attaches to the surface of the steel plate, causing quality problems. There is a problem that dendrite growth becomes more severe during high-speed plating through high current density operations to improve productivity, resulting in a significant increase in defects.

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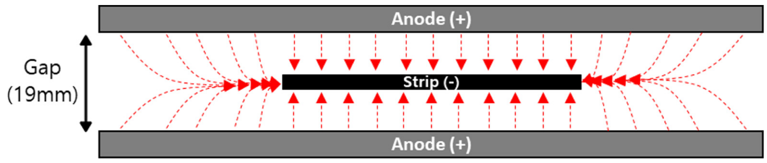


Fig. 1. Current concentration on the edge of steel plate in the LCC-H cell

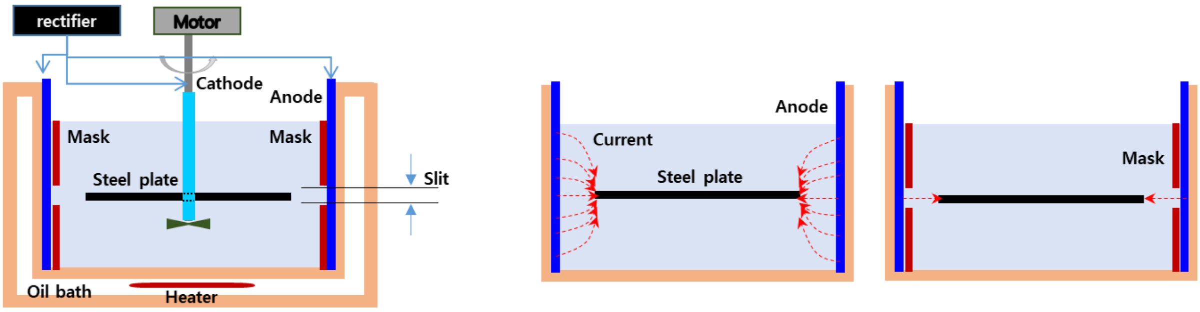


Fig. 2. Schematic diagram of rotary electroplating device (left) and current flow by edge mask (right)

In this paper, we would like to investigate the causes and influencing factors of dendrite plating that occur during high-speed production by high-voltage operation when producing Zn-Ni electroplated steel sheets, which have recently increased in use for digital home appliances and fuel tank of two-wheeled vehicle and find solutions.

2. Experimental

2.1 Fabrication of electroplating devices

The rotary type electroplating device manufactured in this research is composed of a cylindrical insoluble anode and cathode connected to a rotary shaft with an impeller attached, and a temperature-controlled bath, as shown in Fig. 2. The insoluble anode was produced by IrO_2 coating (40 g/m^2) on a cylindrical titanium metal panel (f 124 mm × height 150 mm × thickness 4.0 mm). The cathode axis covers the surface with an acid-resistant metal with a polymer resin, connects a motor to the upper part, and connects a disk-shaped steel plate and an impeller to the lower part. The oil bath is made of stainless steel and has a size in which a cylindrical anode can be inserted. The impeller connected to the anode shaft allowed speed adjustment up to 800 rpm and used an insulating plastic material. The edge mask was manufactured to simulate the dendrite plating phenomenon, that is, to prevent the concentration of current from the anode to the steel plate edges. The material of the edge mask used a 1.0 mm thick polycarbonate film, which is a nonconductive material that could prevent an electric current generated from the anode. Slits of sizes 0, 2, 5, and 10 mm were made on the mask to control the current of the anode.

2.2 Preparation of electroplating solution and experimental conditions

The Zn-Ni electroplating solution used in this paper was a sulfate-based solution with [Zn] 45 g/L, [Ni] 75 g/L, [Na_2SO_4] 35 g/L and pH of 1.5. The plating temperature was carried out under conditions of 40 and 60 ºC and current density was carried out under conditions of 80 and 160 A/dm^2. Experiments were conducted on the effect of i) thickness and cut edge processing methods of steel plate, ii) current density, iii) temperature, flow rate, electrolyte concentration, and pH of plating solution as well as iv) edge mask as factors influencing the generation of dendrite plating by current concentration from anode. Steel specimen disks were manufactured in three ways for dendrite plating simulation according to the cut edge processing method. First, when shearing the steel plate, the edge surface was most rough, and burr occurred a lot. Second, the steel plate was subjected to shearing and polishing treatment, and polishing was performed with G80 sandpaper to remove burr and create a round shape. Third, laser processing was cut in cross-section. Table 1 and 2 show the relative evaluation results based on optical micrographs of dendrite formed on edge of steel plate for various influencing factors. The crystal size and amount of dendrite plating were visually compared and qualitatively evaluated, numerically indicated (worse) 5-4-3-2-1 (good).

3. Results and Discussion

In this paper, a rotary type electroplating device was manufactured to simulate the generation of dendrite due to current concentration at edge of steel plate in a LCC-H electroplating process. The effect of i) thickness and cut edge processing methods of the steel plate, ii) current density, iii) temperature, flow rate, electrolyte concentration, and pH of the plating solution were investigated as factors affecting dendrite plating. In addition, to prevent dendrite plating, iv) an edge mask was manufactured, and its application effect was investigated. Optical micrographs of dendrite formed on edge of steel plate for various influencing factors were summarized as shown in Fig. 3.

3.1 Effect of steel plate

① **Thickness** As shown in the Fig. 3, the thinner the steel plate than when it is thick, the more severe the dendrite is generated.

② **Cut edge type** In general, cold-rolled steels for electrogalvanizing are mill edge processed. The degree of dendrite generation according to shearing, polishing after shearing and laser processing methods was compared. In Fig. 3, when comparing the size and amount of dendrite crystals, shearing > sharing and polishing ~ laser tendency was shown. That is, it was found that the greater the roughness of the cut edge, the more severe the occurrence of dendrite (in the presence of unevenness or burr). In addition, the thinner the thickness of the steel plate, the more severe the occurrence. This result is similar to the severe phenomenon in the production of Zn-Ni electroplated product of thin thickness of steel plate for digital home appliances in the production process.

3.2 Effect of current density

Zn-Ni alloy electroplating is operated under higher current density conditions compared to Zn electroplating. In Fig. 3, the occurrence of dendrite was more severe

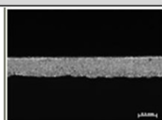
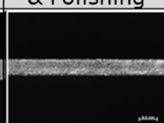
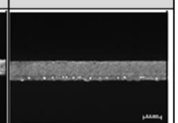
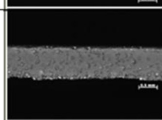
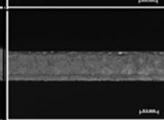
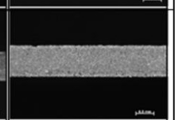
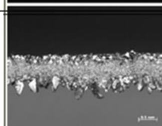
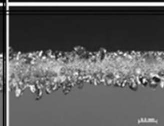
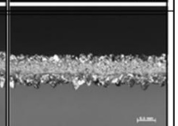
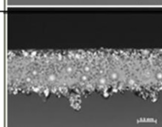
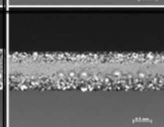
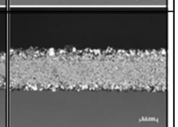
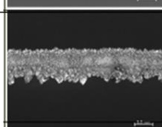
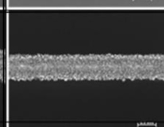
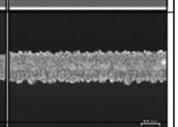
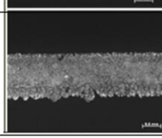
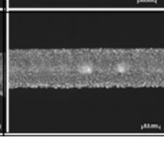
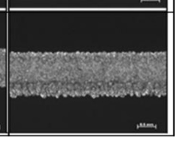
Temp. (°C)	Current density (A/dm^2)	Flow rate (rpm)	Thickness (mm)	Edge Processing Methods of Strip		
				Shearing	Shearing & Polishing	Laser
40	80	140	0.45			
40	80	140	0.8			
40	160	140	0.45			
40	160	140	0.8			
60	160	280	0.45			
60	160	280	0.8			

Fig. 3. Optical micrograph of dendrite formed on edge of steel sheet for various influencing factors

under high current density (160 A/m^2) conditions than at low current density (80 A/m^2), and the thinner steel plate, the more severe the occurrence. This result means that under high current density conditions, current concentration is severe in the edge area of the steel plate.

3.3. Effect of electroplating solution

① **Temperature** In general, when the temperature of the plating bath increases, the activity of ions in the solution becomes active, affecting the generation of dendrites. Fig. 3 shows that the occurrence of dendrites is more severe in low temperature (40 ºC) than in high temperature (60 ºC). Likewise, both the thinner the steel plate and the lower the flow rate, the more severe the occurrence was.

② **Flow rate** In general, it is judged that when the flow rate of the plating bath increases, the generation of dendrite decreases as the supply of ions in the solution becomes easier. Fig. 3 shows that the low speed (140 rpm) condition is more likely to cause dendrites than the high speed (280 rpm). Likewise, the thinner the steel plate, the more severe the occurrence.

③ **Conductivity** In general, electroplating additives are used to improve the electrical conductivity of the plating solution in the electroplating process. In the sulfuric acid bath of this study, sodium sulfate (Na_2SO_4) was added to investigate its effect. When sodium sulfate was added at 0, 1.5, and 3.0% to the plating solution, the electrical conductivity increased to 148, 150, and 154 mS/cm (temperature 60 ºC), respectively. In Table 1, it was confirmed that the difference in the degree of dendrite occurrence was insignificant, but the plated surface of the steel plate was improved.

④ **Zn ion concentration**

For identifying the effect of the electrical conductivity of the plating solution, the degree of dendrite generation was evaluated by adding 0, 2.5, and 5.0% of $ZnSO_4$. In Table 1, it seems that the generation of dendrites tends to decrease slightly, but it is judged that the influence is not significant. To increase the conductivity of the plating solution in operation, an additional cost increase is inevitable, which is not preferable.

⑤ **pH** In general, managing the pH of the plating solution at a low level decreases the overvoltage of hydrogen to prevent reverse charges caused by a leakage current and increase the electrical conductivity, which is expected to affect the generation of dendrites. In this study, 0% (pH 1.54), 1.5% (pH 1.49), and 3.0% (pH 1.47) of sulfuric acid (concentration 96%) were added to the plating solution, respectively. At this time, the degree of dendrite generation slightly decreased as the pH decreased in Table 1. Such a phenomenon is judged to have improved plating property due to improved electrical conductivity.

3.4. Effect of edge mask

Both Fig. 4 and Table 2 illustrate the degree of dendrite generation when adjusting the slit interval of the mask by 0, 2, 5, and 10 mm under conditions where the flow rate of the plating solution is low. When the edge mask is fully closed, the anode current was not transmitted to the steel

Table 1. Summary of effect of conductivity, Zn ion concentration and pH on dendrite generation

Na_2SO_4 (%)	$ZnSO_4$ (%)	H_2SO_4 (%)	Temp. (ºC)	Curr. Density (A/dm^2)	Thickness (mm)	Flow rate (rpm)	Dendrite (Rel. evaluation)	Cut edge
0	-	-	60	20	0.45	30	1	Shearing
1.5	-	-					2	
3.0	-	-					2	
-	0	-	60	20	0.45	30	1	Shearing
-	2.5	-					1	
-	5.0	-					1	
-	-	0	60	20	0.45	30	2	Shearing
-	-	1.5					1	
-	-	3.0					0	

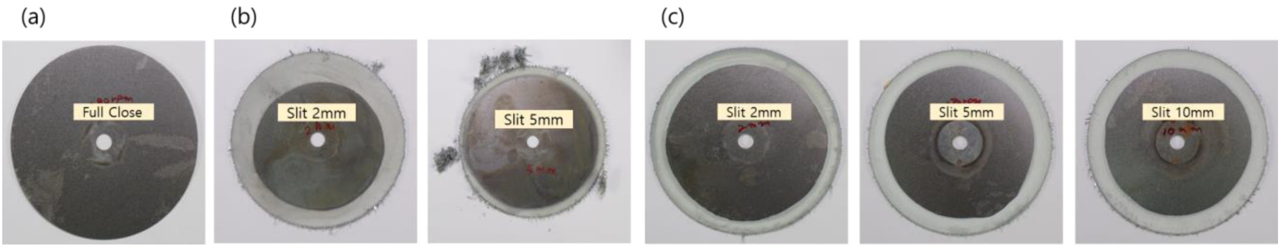


Fig. 4. Effect of edge mask on dendrite generation under (a) full close, (b) low and (c) high flow rate

Table 2. Summary of effect of edge mask on dendrite generation

Temp. (°C)	Curr. Density (A/dm^2)	Thickness (mm)	Flow rate (rpm)	Edge mask Slit size (mm)	Dendrite (rel. evaluation)	Cut edge
60	20	0.45	30	0 (Full close)	0	Shearing
				2	3	
				5	5	
				10	5	
60	20	0.45	280	0 (Full close)	0	Shearing
				2	1	
				5	1	
				10	2	

plate, so plating was not performed, and the degree of occurrence was 0 < 2 << 5 ~ 10 mm depending on the width of the slit. Both Fig. 4 and Table 2 illustrate the degree of dendrite generation when adjusting the slit interval of the mask by 0, 2, 5, and 10mm under conditions where the flow rate of the plating solution is high. Even in this case, when the edge mask was completely blocked, it was not plated as before, and depending on the width of the slit, the degree of occurrence was 0 < 2 ~ 5 < 10 mm, indicating that the smaller the width of the slit, the more effective it is. Overall, dendrites were generated smaller than when the flow rate was low.

4. Conclusion

In electroplating utilizing LCC-H, the dendrite plating is over-coating phenomenon in which crystals grow in a direction that facilitates the supply of metal ions in the plating solution when current is concentrated from the anode (+) of the plating cell to the edge of the steel plate (-). This paper sought to identify the cause of dendrite defects and derive influencing factors in operation to improve productivity of Zn-Ni alloy electroplating products, which have recently been in increasing demand for digital home appliances and fuel tank of two-wheeled vehicle. Overall, the results of this study on the factors affecting the occurrence of dendrites are as follows.

First, the thinner the steel plate, the more likely it is to occur. Second, the edge processing method of steel plates occurs in the order of laser, shearing and polishing, shearing. Third, the higher the current density, the higher the amount of occurrence. Fourth, the lower the temperature of the plating bath, the more severe it occurs. Fifth, the lower the flow rate, the more severe the occurrence. Sixth, the effect of the conductivity additive is small, but the lower the conductivity of the plating solution, the more slightly severe the occurrence. Seventh, the effect of pH of the plating solution is low, but the higher it is, the more severe it occurs. Lastly, the edge mask is very effective in close operation within 5 mm, especially when the plating operation was done at high than at low flow rate.

In conclusion, to reduce dendrite plating during high-speed operation of Zn-Ni electroplating, the processing method of the cut edge part of the steel plate needs to be improved, the temperature needs to be managed as high as possible, and the edge mask needs to be installed in all cells to control proximity.

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