Mechanism and Prevention of Edge Over Coating in Continuous Hot-Dip Galvanizing

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In order to clarify the mechanism of edge over coating (EOC) for continuous hot-dip galvanizing, a visualization test of the gas flow on strip and a cold model test to measure the profile of the coating thickness at the strip edge were carried out. Outward deflected gas flow was observed at the strip edge and EOC developed in the absence of gas wiping. With gas wiping, EOC developing below the wiping position is reduced by the impinging pressure of the gas wiping jet, and the film thickness becomes approximately uniform at the gas wiping position. However, upward of the gas wiping position, EOC increases again and the outward deflected gas flow on the strip edge sweeps the liquid film to the strip edge. EOC is considered to develop at the location where the dynamic pressure of the outward deflected gas flow balances with the surface tension.

For the prevention of EOC, edge masking was devised and the effects which reduce EOC were measured in the cold model test and on a commercial line test. The edge mask which can be kept farther away from the strip edge is more effective for preventing EOC than the edge plates. The optimum dimension of the edge mask is 30 mm in width and 75–100 mm in depth, and installing it at 4–10 mm away from the strip edge is most effective. It was confirmed by the commercial line test that the edge mask can reduce EOC from 45 % to less than 10 %.

KEY WORDS: continuous hot-dip galvanizing; gas wiping; edge over coating; liquid film; coating weight; gas flow pattern.

1. Introduction

In the gas wiping process of continuous hot-dip galvanizing, edge over coating (EOC), that is the coating thickness of the strip edge becomes 1.2–2 times that of the strip center, develops. EOC causes not only coiling trouble but also poor flatness at re-coiling and causes unalloyed edges in the galvannealing process. In order to prevent EOC, several methods have been used.^{1,2)} One example is a concave slit nozzle, of which slit gap faced to the strip edge is wider than the center slit gap. Another is a pair of edge nozzles installed on the main wiping nozzle in opposition to the strip edge. Also, a pair of edge plates or baffle plates are set up near the strip edge parallel to the strip. The method using the concave slit nozzles or the edge nozzles increases the wiping force at the strip edge, so that splashing from the strip edge is promoted and the adhesion of zinc droplets to the strip or to the wiping nozzle results in poor quality galvanized sheets. Though the edge plate or the baffle plate method is effective for preventing EOC if the plates are kept too close to the strip edge, it is difficult to make the plates follow the strip edge and prevent the adhesion of splash.

Umeda *et al.*³⁾ have indicated that the strip edge becomes

cooler than the strip center and the increased viscosity of the coating metal cause difficulty in wiping, and the coating metal on the strip is made to flow to the strip edge by the wiping jet which flows to the free strip edge. Tajiri⁴⁾ has confirmed the deflected wiping gas flow on the strip edge by the wall trace visualization method for an air knife coater.

Hoeflaak⁵⁾ has indicated that non-uniform surface tension causes EOC in the drying process after painting on sharp edges. As the coating at the edge is thin and the solvent evaporates fast, the concentration of the resin, which has a larger surface tension than that of solvent, increases. The difference of surface tension causes paint flow to the edge and results in EOC.

As mentioned above, little investigation on EOC has been performed and the mechanism of EOC has not been made clear. The purpose of this paper is to clarify the mechanism of EOC and to develop prevention methods. The visualization of the gas flow on the strip was carried out by the tuft method and the profile of coating thickness at the strip edge was measured by using the cold model. An edge mask was devised and its effectiveness in preventing EOC was compared with that of the edge plate method. After the shape of the edge mask was optimized by the cold

Fig. 1. Schematics of experimental apparatus.

model test, the preventive effect was confirmed on a commercial continuous hot-dip galvanizing line.

2. Experimental Apparatus and Procedure

2.1. Experimental Apparatus

A schematic of experimental apparatus for the visualization of the flow pattern on a strip is shown in Fig. 1(a). Gas jet from the wiping nozzle is blown onto a 300 mm wide transparent acrylic plate on which 50 mm long woolen string tufts were attached at 50 mm intervals. Near the impinging position of the wiping jet and the plate edge, they were attached with a separation 20 mm. The motion of tufts was observed from the opposite side of the acrylic plate by a still camera. The gas velocity profile on the strip was measured with an 0.51 mm outer diameter and 0.26 mm inner diameter Pitot tube attached to the two dimensional traverser.

Figure 1(b) shows a schematic of the cold model used to measure the coating thickness on the strip. A galvanized endless steel belt, which has a width of 150 mm and thickness of 0.7 mm, is driven by a variable speed motor in the direction of the arrow. The steel belt is pulled up continuously with a liquid film on it through a liquid bath and is wiped by a pair of wiping nozzles installed above. The coating thickness is controlled by the nozzle pressure. The line speed is regulated an arbitrary value in the region of 0–3 m/s.

The shape of wiping nozzle used is shown in Fig. 2. The nozzle slit gap is 1.7 mm and its width is 500 mm for the visualization test and 200 mm for the cold model test. Wiping gas is ambient temperature air which is compressed by a 37 kW screw type compressor and is supplied to the wiping nozzle through a freezer and a filter.

A needle electrode method was employed to measure the coating film thickness. The needle electrode attached to the two dimensional traverser is movable with an accuracy of 0.01 mm. City water, glycerine solution and ethylene-glycol were used as the coating fluid. A little potassium chloride was added to increase electrical conductivity. The physical properties of fluid used are shown in Table 1.

2.2. Shape of Edge Plates and Edge Mask Used

Two kinds of edge plates and an edge mask to prevent

Fig. 2. Shape of gas wiping nozzle used.

Table 1. Physical properties of fluid used.

Liquid	Temp. °C	Density kg/m ³	Viscosity mPa·s	Surface tension mN/m
Water	12	999	1.24	74
66% Glycerine solution	17	1168	17.3	69
74% Glycerine solution	10	1192	63.8	68
Ethylene glycol	10	1115	26.8	37

EOC were tested. One of the edge plates was set up near the strip edge parallel with the strip as shown in Fig. 3(a). The other was set up near the strip edge perpendicularly to the strip as shown in Fig. 3(b). The newly devised edge mask was installed surrounding the strip edge, as shown in Fig. 3(c), in order to control the deflected wiping gas flow on the strip. The parallel and perpendicular edge plate were 40 mm wide and 500 mm long, and were set up at a location of 300 mm above and 200 mm below the impinging position of the wiping jet. The edge mask is 203 mm long and was installed 15 mm above the impinging position of the gas wiping jet.

3. Experimental Results and Discussion

3.1. Wiping Gas Flow on a Strip

The photographs of wiping gas flow on a strip visualized by the tuft method are shown in Fig. 4. The tufts are trailing upward and downward from the impinging line of the wiping gas jet. Though the tufts attached on the strip center are trailing parallel to the strip, the tufts attached at the strip edge are inclined to trail slightly outward from the strip's direction of movement. The deflected wiping gas flow on the strip edge is considered to be one of causes of EOC and edge splashing.

3.2. Condition under Which Edge Over Coating Develops

3.2.1. Without Gas Wiping

Spanwise distributions of film thickness in the cold model test without gas wiping are shown in Fig. 5. Film thickness distributions are defined as the ratio to the thickness of the strip center. Though film thickness of strip center is approximately uniform, the film becomes thicker at 30 mm from the strip edge and becomes maximum at the location of 10–15 mm. In 5 mm from the strip edge, film is thinner than that of the strip center. This tendency is approximately the same regardless of line speed and liquid

Fig. 3. Shape of edge plate and edge mask tested.

Fig. 4. Photographs of gas wiping flow pattern on a strip.

used. The maximum EOC decreases with decrease in surface tension in the order of water, glycerine solution and ethylene glycol. This phenomenon suggests that surface tension of the liquid also causes EOC.

Figure 6 shows the difference of EOC with height from the bath surface. Near the bath surface, the liquid film in the region of 5 mm from the strip edge is slightly thicker than that at a higher position but the maximum film thickness is lower. The maximum EOC at lower positions develops near to the strip edge than higher positions.

Figure 7 shows the relationship between the location of the maximum EOC and the height from the bath surface. The location of the maximum EOC moves to the strip center from the strip edge with the height from the bath surface

Fig. 5. Distributions of relative coating thickness without gas wiping.

Fig. 6. Effect of height from bath surface on edge over coating without gas wiping.

and it becomes constant 10–15 mm from the strip edge above 350 mm from the bath surface.

3.2.2. With Gas Wiping

Spanwise distributions of film thickness with gas wiping are shown in Fig. 8. In this case, a pair of the wiping nozzles were installed at a height of 485 mm above the bath surface and the line speed was 0.85 m/s. In addition, the film thickness distribution without gas wiping is indicated by a broken line. EOC below the wiping position (at a

height of 300 and 400 mm from the bath surface) was about 20% and the location of the maximum EOC is 10–15 mm from the strip edge, the same as that without gas wiping. EOC immediately above the wiping position (at a height of 500 mm above the bath surface, that is at a height of 15 mm above the wiping nozzle) is reduced to less than 10%. However, EOC at a height of 115 mm above the wiping nozzle (at a height of 600 mm above the bath surface) grows to 40–50%. EOC with gas wiping becomes larger than that without gas wiping, and the location of the maximum EOC moves to the strip edge. At the location toward the strip center from the location of EOC, the liquid film

Fig. 7. Location of maximum edge over coating without gas wiping.

Fig. 8. Distributions of relative coating thickness with gas wiping.

Fig. 9. Model of edge over coating.

Fig. 10. Effects of edge plates and edge mask on restraint of edge over coating.

thickness has a tendency to become slightly thin. This is considered to develop due to the deflected wiping gas flow on the strip edge sweeping away the liquid film to the strip edge.

3.3. Mechanism of Edge Over Coating

From the above, the mechanism of EOC can be considered as shown in Fig. 9. Namely, the liquid adhering to the strip side flows around the strip surface by surface tension. This phenomenon occurs in case without gas wiping. This EOC is reduced by the impinging pressure of the gas wiping jet, and the film thickness at the strip edge becomes approximately uniform at the gas wiping position. Above the gas wiping position, the liquid adhering to the strip side flows around the strip surface and EOC increase again. The outward deflected gas wiping flow on the strip edge sweeps the liquid film to the strip edge and EOC is considered to develop at the location where the dynamic pressure of the deflected gas flow balances with the surface tension. So, in order to prevent EOC, it is important to control the outward deflected flow at the strip edge.

3.4. Prevention of Edge Over Coating

3.4.1. The Restraining Effects of Edge Over Coating by Edge Plates and Edge Mask

The restraining effects of EOC by two kinds of edge plates, that is the parallel and the perpendicular edge plate, and the edge mask are shown in Fig. 3. The parallel edge plate is slightly effective for preventing EOC, when it is

Fig. 11. Effective dimensions of edge mask to reduce edge over coating.

kept within 2 mm of the strip edge. However, it becomes ineffective when kept 5 mm apart from the strip edge. The perpendicular edge plate is scarcely effective even if it is kept 3 mm away from the strip edge.

As compared with the edge plates, the edge mask is more effective for preventing EOC, when kept 7 mm away from the strip edge. However, when kept 13 mm away from the strip edge, the restraining effect on EOC is reduced.

The conditions for EOC with the edge mask is different from that with the edge plate. The maximum EOC with the edge plate located 4–8 mm from the strip edge as same as the case without the edge plate. However, in the case with the edge mask, the location of the maximum EOC moves nearer to the strip edge, and it develops 3–4 mm in from the strip edge. This is considered to result from the gas flow on the strip edge being controlled by surrounding the strip edge with the edge mask.

As mentioned above, it was clear that the edge mask was more effective in preventing EOC than the edge plates because the edge mask can be kept farther away from the strip edge. Keeping the edge mask farther away from the strip edge facilitates the positioning and the prevention of splash adhesion, so the edge mask is also more practical than the edge plate.

3.4.2. Optimum Dimensions of Edge Mask

Figure 11 shows the effect of the dimensions of the edge mask on EOC reduction. It was evaluated using an open circle (○) to indicate that the maximum EOC is less than 10%, by an open triangle (△) to indicate it is 10–20%, and by an ex (×) to indicate it is more than 20%.

From this figure it was concluded that the optimum dimensions of the edge mask are less than 40 mm in width and more than 50 mm in depth in order to reduce EOC to less than 10%. With these dimensions, the prevention of EOC is seen when the edge mask is installed less than about 10 mm away from the strip edge.

3.4.3. Control of Gas Flow on Strip by Edge Mask

Figure 12 shows the velocity distribution of the gas flow on the strip with an edge mask installed on one side of the strip edge. The edge mask used was 30 mm in width, 50 mm in depth and 203 mm in length, and the setup distance from the strip edge was changed between 5, 10 and 15 mm. The spanwise velocity distributions were measured at the

Fig. 12. Velocity profile of gas flow on a strip with and without edge mask.

outlet of the edge mask and at the position of 7.5 mm above the strip surface. The vertical velocity distributions were measured at three positions, 3 mm from each strip edge and at the strip center. The velocity distributions are shown as the ratio to the nozzle outlet velocity.

Without the edge mask (on the right side of Fig. 12), the gas velocity on the strip begin to decrease from a position of about 30 mm from the strip edge and the gas velocity at the strip edge was 30–40% lower than that at the strip center. This is considered to be caused by the outward deflected gas flow. On the other hand, the gas velocity on the strip edge with the edge mask increased 50–60% higher than that of the strip center. This shows that the edge mask controlled the outward deflected gas flow and restrained EOC. However, the increases in the gas velocity on the strip edge by the edge mask are similar independent of the edge mask

Fig. 13. Velocity profile of gas flow on a strip edge with edge mask.

Fig. 14. Test setup of edge mask in a commercial line.

setting location and the difference of the gas velocity profile is not obvious from Fig. 12 between the case that EOC was reduced by setting the edge mask 5 or 10 mm from the strip edge and the case that EOC was not reduced by setting the edge mask 15 mm from the strip edge. The enlargement of the velocity profiles on the strip edge with the edge mask is shown in Fig. 13. From this figure, the difference of the uniformity in the gas velocity profile on the strip edge is observed. Where the distance from the strip edge to the edge mask is 5 or 10 mm, under which conditions the effect of EOC reduction was seen, the gas velocity profile on the strip in the region of about 10 mm from the strip edge is nearly uniform. When the edge mask was installed 15 mm away from the strip edge, under which conditions the reduction of EOC was not seen, the gas velocity profile is not uniform.

Though it is not concluded that the uniformity of the gas velocity profile on the strip edge has directly effects upon EOC reduction, it is clear that the edge mask controls the gas flow on the strip edge and restrains EOC in case that it is installed in the optimum distance from the strip edge. When the edge mask is installed in keeping away from the strip edge, it may be considered that the outward deflected gas flow occurs again and EOC develops. In order to clear the mechanism of EOC reduction by the edge mask, it is necessary to examine the gas flow profiles and the pressure distributions on the strip edge in more detail.

4. Commercial Line Test

4.1. Shape of Edge Mask Tested and Test Conditions

The 500 mm long edge mask was installed in a commer-

Table 2. Test conditions for commercial line test.

Strip			Operating conditions				
Thickness mm	Width mm	Coating weight g/m ²	Line speed m/min	Nozzle-strip distance mm	Nozzle height mm	Nozzle pressure kPa	Gas temp. °C
0.48	910	40	133	18 - 22	490	13.7	100
- 1.00	- 1000	- 140	- 150	-	- 530	- 35.5	-

Fig. 15. Effect of edge mask on reduction of edge over coating. (Commercial line test)

Table 3. Optimum shape of edge mask (Commercial line test).

Shape of edge mask			Edge-mask to strip-edge dist.					
Width We(mm)	Depth De(mm)	Length Le(mm)	ΔS (mm)					
			2	4	6	8	10	12
30	50	500	Δ	Δ	Δ	×	×	×
	75		Δ	○	○	Δ	Δ	Δ
	100		×	○	○	○	○	Δ
40	75		Δ	×	×	Δ	Δ	Δ

cial continuous hot-dip galvanizing line with a support frame and it was kept at a constant distance from the strip edge by a touch roll as shown in Fig. 14. The edge masks which were 30–40 mm in width and 50–100 mm in depth were tested. Test conditions are shown in Table 2. The line speed was 133–150 m/min and the nozzle pressure was varied from 13.7 to 35.5 kPa in order to keep the coating weight at 40–140 g/m² (5.6–19.6 μm in thickness) which is the usual thickness that galvanized sheets are produced at.

4.2. Reduction of Edge Over Coating on a Commercial Line

The comparison of the coating weight profile with and without the edge mask is shown in Fig. 15. The coating weight profile was measured by dissolving zinc on each sample, which was cut to 10 mm wide from the galvanized sheet tested, in dilute hydrochloric acid. It is clear that the edge mask reduced EOC from 45% to less than 10%. Table 3 shows the results from evaluating the dimension of the edge mask. The maximum EOC indicated by an open circle (○) is less than 10%, an open triangle (Δ) indicates that there are satisfactory and unsatisfactory samples, and an ex (×) indicates completely unsatisfactory samples. From Table 3, it was concluded that the optimum dimension of the edge mask for preventing EOC is 30 mm in width and 75–100 mm in depth and keeping the edge mask at 4–10 mm from the strip edge is most effective.

5. Conclusions

In order to clarify the mechanism of edge over coating (EOC), a visualization test of the gas flow on the strip and a cold model test to measure the profile of coating thickness at the strip edge were carried out. For the prevention of EOC, the edge masking was devised and the reduction of EOC was measured in the cold model test and the commercial line test. The results may be summarized as follows:

(1) Though the gas wiping flow on the strip center is parallel to the strip, outward deflected gas flow is observed at the strip edge.

(2) Without gas wiping, EOC develops and the location of the maximum EOC moves from the strip edge to the strip center with the height from the bath surface and it becomes constant above 350 mm high.

(3) With gas wiping, though EOC occurred in the same manner as in the case without gas wiping below the wiping position, it is reduced to less than 10% immediately above the wiping position and then increases to 40–50% again. EOC with the gas wiping becomes larger than that without gas wiping and the location of the maximum EOC moves to the strip edge.

(4) The mechanism of EOC can be considered as follows. The liquid adhering to the strip side is made to flow around the strip surface by surface tension and EOC develops. This EOC is reduced by the impinging pressure of the gas wiping jet and the coating thickness becomes approximately uniform at the gas wiping position. However above

the gas wiping position, EOC increases again and the outward deflected gas flow on the strip edge sweeps the liquid film to the strip edge and EOC is considered to develop at the location where the dynamic pressure of the deflected gas flow balances with the surface tension.

(5) The edge mask is more effective for preventing EOC than the edge plates because the edge mask can be kept farther away from the strip edge. The installation of the edge mask to keep farther away from the strip edge facilitates the positioning to the strip edge and the prevention of splash adhesion, so the edge mask is more practical than the edge plate.

(6) The optimum dimensions of the edge mask are 30 mm in width and 75–100 mm in depth and installing 4–10 mm away from the strip edge is most effective for preventing EOC. It was confirmed by the commercial line test that the edge mask can reduce EOC from 45% to less than 10%.

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