Accurate Fabrication by Improvement of Lamination Path on Direct Metal Lamination Using Arc Discharge

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INTRODUCTION
Direct metal lamination using arcl discharge has been developed by the authors' research group [1] as a Rapid Manufacturing (RM) technology. In this method, the metallic materials are melted and accumulated by arc welding technology. Therefore, various metallic materials can be used. The strength is better than the bulk material, so metallic products with high strength can be fabricated rapidly. In addition, the laminated modeling objects can be fabricated as a near net shape. So this method can reduce the quantity of the consumed material and is especially expected to fabricate the large-size dies and the single machine part which needs high-strength. Generally, in RM processes, 3D-CAD data is transformed into 2D-sliced data. This data is used to make the sliced shape data for the layer manufacturing. In the direct metal lamination, the switching on and off of the welding power supply often causes the unintended steps on the manufactured surface. Therefore, general laminating processes decrease the dimension accuracy. In addition, when an inclined wall shape is fabricated, its inclined angle becomes larger than the setting angle [2]. In this study, continuous lamination path is generated from 3D-CAD data. In addition, the laminated modeling object which has inclined angle is fabricated using the continuous lamination path. Then, measured inclined angle is compared with setting angle. Finally, the angular error is compensated by the modified lamination path.

EXPERIMENTAL PROCEDURE
Fig. 1 shows the direct metal lamination machine. It has four axes X, Y, Z and B. A welding torch is attached on Z axis. A substrate 150 mm × 150 mm × 5 mm in size, on which the manufacturing object is accumulated, is fixed to the base block on the table. The molten metal produced by the arc electrical discharge is dropped and deposited on the substrate from the welding torch tip. Z axis is controlled according to the height of the accumulating point.

FIGURE 1. Experimental procedure

FIGURE 2. Influence of the lamination path on the modeling accuracy

FIGURE 3. Flow chart of generating spiral path

GENERATION OF THE SPIRAL PATH FROM 3D-CAD DATA
In the direct metal lamination, the bead height near the lamination start point is high. On the other hand, the bead height near the lamination end point is low. Therefore, the height of laminated modeling object becomes uneven with existing discontinuous lamination path as shown in Fig. 2(a). In this study, a spiral path is applied to the fabrication of shell structures. The spiral path continues the lamination from the beginning of the fabrication to the end. The spiral path can be calculated as shown in Fig. 3. With the spiral path, the height of the laminated modeling object could be fabricated without discontinuity as shown in Fig. 2(b).

DETERMINATION OF LAMINATION PATH
Measurement of the inclined angle
In this section, the laminated modeling object whose inclined angle was continuously changed
In order to compensate the angular error, a response surface method was applied because various factors interact and causes the angular error. Setting angle $\theta'$ is calculated from target angle $\theta$ and torch feed speed $F$ with follow equations.

Without cooling:
\[
\theta'_{\text{C-co}} = -5.14 + 0.980\theta - 3.58 \times 10^{-3}\theta^2 - 3.99 \times 10^{-6}\theta^3 \\
\theta'_{\text{C-co}} = -4.22 + 0.937\theta + 0.0279f
\]

With water cooling:
\[
\theta'_{\text{C-co}} = -2.58 + 1.090\theta + 0.0345f \\
\theta'_{\text{C-co}} = -2.60 \times 10^3\theta - 3.21 \times 10^2\theta^2 - 7.94 \times 10^{-3}\theta^3 \\
\theta'_{\text{C-co}} = -2.68 + 0.9170 + 0.0169f
\]

Then, the laminated modeling object was fabricated by the modified spiral path. Torched feed speed $F$ was 200mm/min. Figure 7 shows the result of the compensation. From this figure, the angular error was 22% decreased.

**CONCLUSIONS**

1. With the spiral path, the laminated modeling object can be fabricated continuously with high accuracy.
2. The angular error tendency depends on inclined angle, welding torch feed speed, cooling method and torch feed direction. 
3. The angular error was decreased 22% by the compensation using the relationship obtained by the response surface method.

**REFERENCES**
