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Development of magnetic polishing method of aspherical shape using small ball end mill type tool

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Abstract
Plastic components with a complex shape such as an aspherical shape or a free-form shape are used in various electrical appliances. These components are fabricated in a mold that is machined with cutting and grinding. This mold is typically polished using a polishing method such as lapping after it is formed into the desired shape to improve the surface roughness of the machined surface. However, this polishing method has many problems. Therefore, in this study, a new polishing method that polishes the mold with a ball-shaped permanent magnet tool on a 5-axis machining center is proposed. An aspherical mold made of brass was experimentally polished, and the form deviation and surface roughness were measured. The mirror surface was obtained, and the form accuracy was maintained using 4-axis-controlled magnetic polishing. The effectiveness of this proposed 4-axis polishing method was determined. In addition, by changing the size of the magnetic particle or abrasive, further improvement of the surface roughness can be expected.

magnetic polishing, mold, aspherical shape, machining center

1. Introduction

Plastic parts with complex shapes such as aspherical or free-form shapes are used for various products. Typically, these plastic parts are fabricated using a mold that is machined into the desired shape by cutting and grinding. Additionally, these molds are polished using a loose abrasive (slurry) method such as lapping to improve the surface integrity. However, this polishing method has many problems. First, it is difficult to maintain the form accuracy. In addition, the environment deteriorates easily because the slurry is scattered. Finally, a specific-purpose machine for polishing is needed. Therefore, in this study, a magnetic polishing method using a small ball end mill tool made of a permanent magnet on a small 5-axis machining center is proposed [1]. It is easy to introduce this polishing method using a general machining center. Especially, it is considered that this proposed method is useful to fabricate the trial product. In addition, in this method, because a magnetic paste that includes abrasives is held to the tool, the paste does not scatter. Two types of a control method for the magnetic tool (3-axis and 4-axis) are proposed. The polishing results of an axisymmetric aspherical mold made of brass that was polished with the proposed method are provided in this report.

2. Proposed polishing methods

A small magnetic polishing tool made of a permanent magnet, the magnetic paste that is held to the tool, and the small-sized 5-axis machining center that was used are shown in Fig. 1. The tool is attached to the spindle of the machining center. The paste is composed of magnetic fluid; magnetic particles (Fe, diameter: 100 µm); white alumina particles (diameter: 0.1 µm); surfactant; and kerosene [2, 3]. Because this magnetic paste is lightly applied to the tool tip using the permanent magnet, the paste does not scatter. Moreover, because the shape of the paste changes along with the workpiece shape, it is easier to control the abrasives compared with loose abrasives.

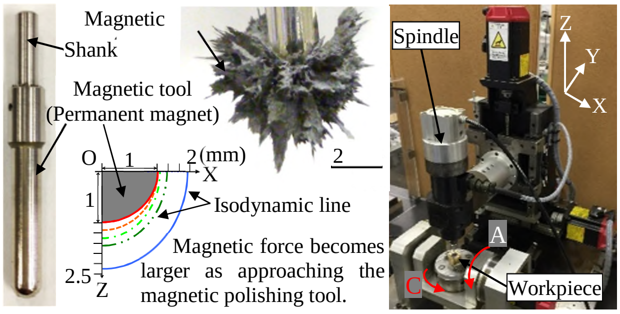
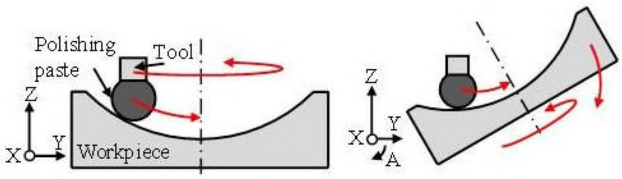


Figure 1. Magnetic polishing tool and paste and 5-axis machining center.

Figure 2 shows the tool-controlling methods. In the 3-axis-controlled method, the tool is controlled like a contour line. However, in the 4-axis-controlled method, the tool and workpiece are simultaneously controlled. Thus, the contact position of the tool (polishing paste) is constantly maintained at all polishing points on the workpiece. Figure 3 shows the model diagram of 4-axis controlled method, and Eq. (1) gives the coordinate values of the tool. Additionally, Eq. (2) provides the aspherical formula, where C_v, K, and C_i (i = 1, ..., n) are aspherical constants; A_O is the A-axis center; and ϑ is the inclination angle of the workpiece and is defined in Eq. (3), provided that Z_{AO} includes the polishing paste gap, which is the distance between the tool tip and the workpiece surface.



(a) 3-axis-controlled method (b) 4-axis-controlled method
Figure 2. Schematic illustration of proposed polishing method.

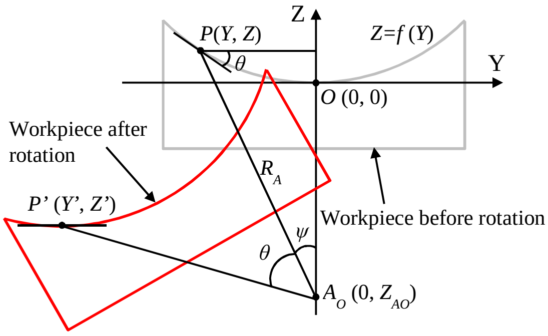


Figure 3. Model diagram of 4-axis-controlled polishing method.

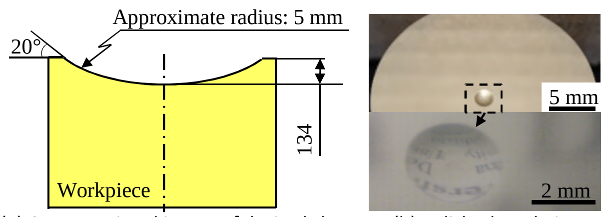
$$\left.\begin{aligned} Y' &= R_A sin(\theta + \psi) \\ Z' &= Z_{AO} - R_A \cos(\theta + \psi) \end{aligned}\right\} \quad (1)$$

$$Z = f(Y) = \frac{Y^2 \cdot C_v}{1+\sqrt{1-(K+1)Y^2 \cdot {C_v}^2}} + \sum_{i=1}^{n} C_i \cdot Y^i \quad (2)$$

$$\theta = \tan^{-1}\{f'(Y)\} \quad (3)$$

3. Experimental results and discussion

For the polishing experiment, the axisymmetric aspherical mold made of brass (C2600) that was fabricated with the machining center was polished. Figure 4(a) shows the cross-sectional illustration of the desired shape. For the aspherical shape, the effective diameter is 1.5 mm, the height is 0.134 mm, and the maximum inclination angle is 20°. Additionally, the polishing conditions are as follows: the magnetic polishing tool radius is 1 mm, the tool rotation speed is 1500 min^{-1}, the tool feed speed is 5 mm/min, the C-axis rotational speed is 140-1080 °/min, and the distance between the magnetic polishing tool tip and the workpiece is 0.3 mm. The rotational speed is changed in accordance with the distance from the workpiece center to maintain a constant polishing time per unit area. The polished workpiece that was polished using the 4-axis polishing method is shown in Fig. 4(b). The cutter mark caused by the ball end milling was removed, and the mirror surface was obtained. In the general lapping method, the addition of the slurry is needed. Whereas, addition or substitution of the paste was not carried out in this experiment.



(a) Cross-sectional image of desired shape (b) Polished workpiece

Figure 4. Images of desired shape and polished workpiece.

Figure 5 shows the form deviation profile, which compares the before-and-after polishing. This result was measured with the contour shape measuring instrument SURFCOM 130A (TOKYO SEIMITSU). The form deviation is worse in the 3-axis polishing method compared with the 4-axis polishing method. In the 3-axis method, because the tool contact point (which depends on the distance from the workpiece center) changes, the polishing pressure or circumferential speed of the tool is different at each polishing point. However, in the 4-axis polishing method, because equal polishing conditions are retained on the entire workpiece surface by maintaining a constant tool contact point, it is considered that the form accuracy which was obtained by ball end-milling was maintained.

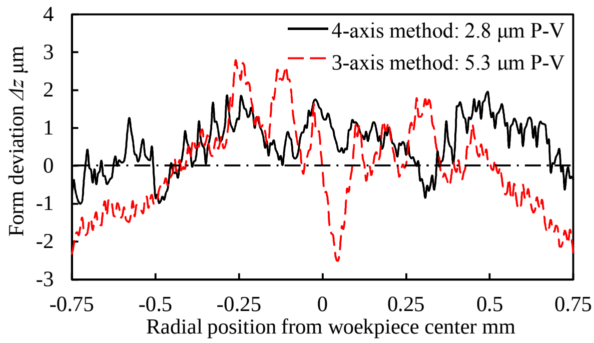
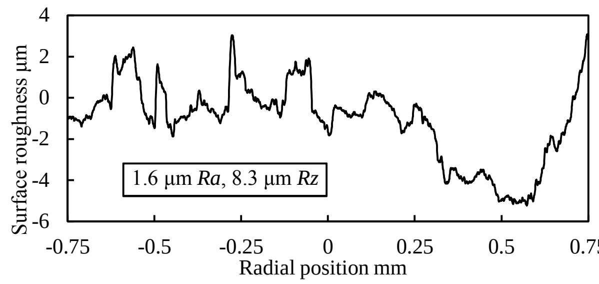
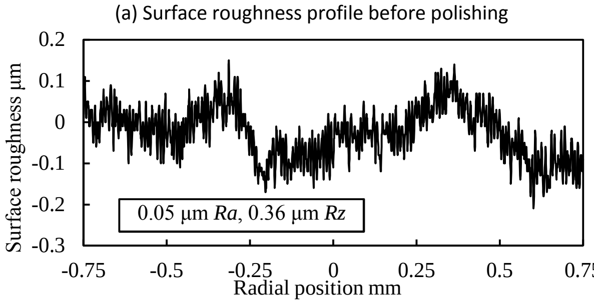


Figure 5. Comparison of form deviation profile.

The surface roughness profile before polishing is shown in Fig. 6(a), and Fig. 6(b) shows the surface roughness profile after polishing for 20 min (two paths). These profiles were measured with the surface roughness measuring instrument E-35B (TOKYO SEIMITSU). The surface roughness improved to 0.05 μm *Ra* (0.36 μm *Rz*) from 1.6 μm *Ra* (8.6 μm *Rz*)—in other words, the surface integrity was increased by approximately 1/30. However, the surface roughness was 0.04 μm *Ra* (0.3 μm *Rz*) after polishing for 60 min. Therefore, it was found that this surface roughness value is the lowest attainable value with the magnetic polishing paste used in this experiment. To further improve the surface integrity, the diameter of the magnetic particles or abrasives needs to be downsized.



(a) Surface roughness profile before polishing



(b) Surface roughness profile after polishing (polishing time: 20 min)

Figure 6. Comparison of surface roughness profiles.

4. Conclusion

In this report, a novel magnetic polishing method using a machining center was proposed. It was determined from the experimental results that the 4-axis polishing method was effective in terms of maintaining the form accuracy and surface roughness. However, it was also found that the magnetic paste needs further improvement.

References

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