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Process time for fabrication of lens-array mold by electrical discharge machining

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Abstract
To efficiently produce lens array molds, we previously proposed a method for shaping the elements of a lens array mold by electrical discharge machining (EDM). In our method, a number of electrodes are arranged side by side to construct an electrode for EDM. This electrode enables the simultaneous shaping of multiple optical elements on a mold surface. In our previous study, we developed a multiple-ball electrode, which includes three conductive balls as discharge areas. To demonstrate the effectiveness of the multiple-ball electrode, a lens array mold with 48 elements was shaped using it. As a result, the mold was successfully shaped with high shape accuracy and a high removal rate. The process time of the mold when using the three-ball electrode was less than one-quarter of that when using a single-ball electrode. In the present study, to clarify the reasons for the high removal rate obtained by our electrode, workpieces were processed using rod-type electrodes with various diameters. It was found that the removal rate increases with both increasing discharge area and increasing number of rods. According to these findings, the reason why the high removal rate was obtained for the three-ball electrode is probably the multiple discharge areas as well as the large discharge area.

Keywords: Lens array, Mold, Machining, Electrical discharge machining, Optical fabrication

1. Introduction

In the general fabrication process of a lens array mold, considerable time and labor are required to shape the optical surfaces; a numerical control machine tool is used in the shaping step, in which each element is shaped individually by feeding the tool precisely. To efficiently produce lens array molds, we previously proposed a method for shaping the elements of a lens array mold by electrical discharge machining (EDM) [1]. Since EDM can remove hard materials more easily than precision grinding and cutting, molds can be efficiently produced. In our proposed method, the electrode is constructed by arranging conductive spherical balls on a baseplate in an array [2]. By using this electrode in the EDM process, a number of lens elements can be simultaneously shaped on a mold surface to produce the mold efficiently. In a previous study [3], we developed a multiple-ball electrode involving three conductive balls. Using the electrode, we processed a lens array mold made of stainless steel with 16 spherical elements, each having a maximum depth of 500 µm. As a result, a mold surface was successfully shaped with a peak-to-valley shape accuracy of better than 20 µm and an average surface roughness of approximately 0.9 µm. The shape accuracy and roughness of the surface processed by the three-ball electrode were almost the same as those for a single-ball electrode [2, 3]. Moreover, the experimental results demonstrated that the multiple-ball electrode enables the shaping of multiple lens elements with a short process time. The present study is performed to clarify the reasons for the short process time for the multiple-ball electrode.

2. Fabrication of lens array mold by EDM with spherical ball electrode

In the previous study, we proposed a spherical ball electrode and a fabrication method for a lens array mold using the electrode. Figure 1 schematically shows the principle of our proposed fabrication method using the electrode. In general, a lens element of a lens array is not a full hemisphere but part of a hemisphere. When the parts of hemispheres are shaped by the electrode shown in Fig. 1, the elements must be generated at intervals; Fig. 1 schematically shows that the elements are produced with an interval of one element in each EDM process. Therefore, to produce a lens array mold whose elements are densely arranged, the EDM process must be repeated to fill the intervals with elements.

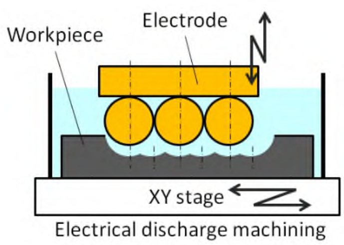


Figure 1. Fabrication of lens array mold by EDM.

In the previous study, we developed a multiple-ball electrode involving three balls and performed fabrication experiments using the electrode. The balls were made of copper and their diameter was 4 mm. Using the electrode, a lens array mold with 48 elements was successfully shaped. Moreover, the experimental results demonstrated that the multiple-ball electrode enables the shaping of the lens elements with a short process time; Fig. 2 shows a comparison of the removal time of three lens elements using single-ball and three-ball electrodes. As shown in Fig. 2, the process times for the single-ball electrode and three-ball electrode were 19.7 min and 15.4 min, respectively. This indicated that the process time of a lens array mold can be reduced by approximately 22% when the three-ball electrode is used instead of the single-ball electrode.

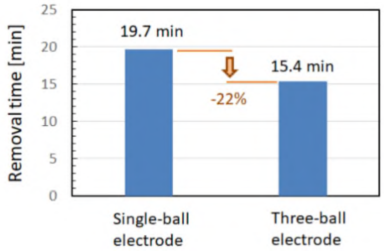
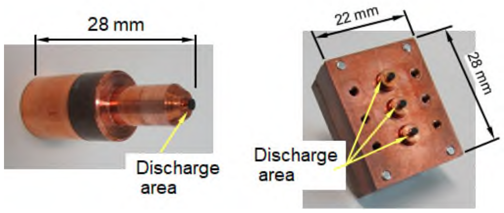


Figure 2. Removal time of three lens elements for single-ball and three-ball electrodes.

The aim of the present study is to clarify the reasons for the reduction of the process time. In the actual fabrication process of a lens element, the discharge area of the ball electrode increases gradually to form the spherical shape of the lens element into a workpiece surface. Thus, to simply model this process, the machining is carried out using rod-type electrodes with various diameters in this study.

3. Experimental method

Two types of electrode (single-rod and three-rod electrodes) were used in this study, as shown in Fig. 3. The electrodes were made of copper, whose end surface was a discharge area in the EDM process. Rods with different diameters were prepared for the two types of electrode.



(a) Single-rod electrode (b) Three-rod electrode

Figure 3. Photographs of single-rod and three-rod electrodes used in the removal experiment.

Stainless-steel plates were used as the workpieces. The workpiece surfaces were prepared by grinding to a flatness of approximately 2 µm over a distance of 40 mm. The workpieces were set on the electrical discharge machine with a parallelism of below 4 µm over 40 mm along the x and y directions of the stage of the machine. In the EDM process, the electrode was moved in the vertical direction to fabricate blind holes with a depth of 0.25 mm. The electrical discharge conditions were the same as those for the fabrication of lens elements by the ball-type electrode. After the EDM processes, the shape of the blind holes was measured using a three-dimensional measuring instrument employing a laser probe (Mitaka Kohki Co., Ltd., NH-3) to calculate the removal volume. The removal rate was calculated from the removal volume and removal time.

4. Results and discussion

Figure 4 Figure 4 shows the experimentally obtained relationships between the diameter of the rod and the removal rate for the two types of electrode. The diameter of the lens elements fabricated in the previous study was approximately 2 mm. Thus, in this experiment, we used rods with a maximum diameter of 2 mm. As shown in Fig. 4, the removal rate for the three-rod electrode is larger than that for the single-rod electrode for the same diameter of the electrode. This result confirms that the lens array mold is fabricated in a shorter process time using an electrode with multiple discharge areas. Moreover, it was found that the removal rate increases with increasing diameter for the two types of electrode, as shown in Fig. 4. Therefore, one possible reason why the removal rate for the three-rod electrode is larger than that for the single-rod electrode is the increase in the discharge area. This probably results from the increase in the probability of the discharge in the EDM process owing to the larger discharge area.

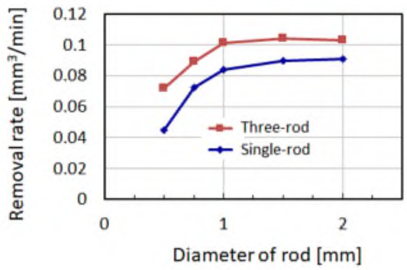


Figure 4. Change in removal rate with increasing diameter of rod for single-rod and three-rod electrodes.

Next, we investigated the dependence of the removal rate on the number of rods. Figure 5 shows the relationships between the total discharge area of the rods and the removal rate for the two types of electrode. As shown in Fig. 5, the removal rate for the three-rod electrode is larger than that for the single-rod electrode for the same total discharge area. It is possible that the emission of chips generated from the gap between the electrode and the workpiece surface occurs more easily for the three-rod electrode than for the single-rod electrode, which leads to the increase in the removal rate for the three-rod electrode.

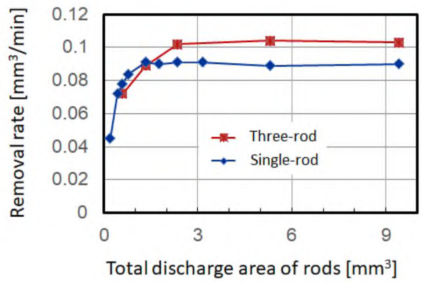


Figure 5. Change in removal rate with increasing total discharge area of rod for single-rod and three-rod electrodes.

5. Conclusions

We developed a multiple-ball electrode in a previous study that includes three conductive balls as discharge areas. The multiple-ball electrode enables the shaping of lens elements in a short time. In the present study, to clarify the reasons for the high removal rate obtained by our electrode, workpieces were processed using rod-type electrodes with various diameters. Two types of rod electrode were used in this experiment: single-rode electrodes and three-rod electrodes. The experimental results showed that the removal rate increases with both increasing discharge area and increasing number of rods. According to these findings, the reason why a high removal rate was obtained for the three-ball electrode is probably the multiple discharge areas as well as the large discharge area.

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