euspen's 15th International Conference & Exhibition, Leuven, Belgium, June 2015
www.euspen.eu

Forming of microlens array mold by indentation method

Hideo Takino[1], Shingo Takagi[1], Yuuki Sakamoto[1], and Yuki Shimazaki[1]

[1] *Chiba Institute of Technology, Japan*

takino.hideo @it-chiba.ac.jp

Abstract

In the general fabrication process of a microlens array mold, considerable time and labor are required for the shaping of 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, in this study we propose an indentation method for forming lens elements on a mold surface. In this method, a flat sintered metal plate is used as a workpiece. The plate is indented by an indenter that is shaped to a lens element profile. Repeating the indentation process enables a number of lens elements to be rapidly produced on the mold surface. If the metal plate is too soft for the mold, the electroforming of the indented surface is performed to produce a hard surface. Aspherical shapes can be formed if a rod with an aspherical tip is used. In this study, we fundamentally investigated the characteristics of our method. To this end, we developed an indentation machine, in which a worktable can be lifted up to a rod facing the worktable through a numerical controller. At the tip of the rod, a tungsten carbide ball with a diameter of approximately 1 mm is fixed for use as an indenter. Using the machine, we processed single impressions, i.e., lens elements, on a porous sintered pure aluminum surface with various indentation loads. The shapes of the impressions were measured by a surface profiler. The experimental results demonstrated that impressions with spherical profiles were successfully shaped by our method. The shape of the impressions was varied by controlling the indentation load. The resulting impressions had shape errors of approximately 1 to 2 µm for a depth of up to approximately 140 µm.

Keywords: lens array, mold, indentation, indenter, surface, optical fabrication

1. Introduction

In the general fabrication process of a microlens array mold, a mold blank is shaped by cutting or grinding to generate an optical surface, which is then polished to a smooth surface. In the shaping step, a numerical control machine tool is used, in which each element is shaped individually by precisely feeding a cutting tool or a grinding wheel. Thus, the existing shaping process requires considerable time and labor, the reduction of which is desired.

To efficiently produce lens array molds, some methods based on plastic forming have been proposed [1-3]. In these methods, a number of impressions are generated on a workpiece surface by repeated indentation; these impressions become the lens elements of the mold. Forest et al. proposed a method in which a rough cut with a ball-end mill is first performed, and then the shape and sag height are achieved by pressing a tungsten-carbide sphere into the milled divot [1]. This method was also investigated by Kobayashi et al. [2]. Yan et al. proposed a method combining micro-nanoindentation and ultraprecision cutting, in which micro-nanoindentation was first performed to form dimples, and then the burrs generated around the dimples were removed by ultraprecision cutting with a diamond tool [3].

In the present work, we propose an indentation method for forming lens elements on a mold surface, which uses a flat sintered metal plate as a workpiece. The plate is indented by an indenter shaped to a lens element profile. To fundamentally investigate the characteristics of our method, we formed impressions, i.e., lens elements, on a surface with various indentation loads.

2. Experimental method

Figure 1 shows a schematic of our newly developed indentation machine. The machine consists of XY and Z stages, a load sensor system, a worktable with a tilt stage, and an indenter fixed on a rod. In this study, a tungsten carbide ball with a diameter of approximately 1 mm is used as the indenter.

To generate impressions on a workpiece, a workpiece placed on the worktable can be lifted up to the indenter through a numerical controller. After generating one impression, the workpiece is moved by the XY stage to generate the next impression. The repetition of this procedure enables the production of a lens array mold surface.

In this study, we created single impressions for various indentation loads using the machine shown in Fig. 1. The shapes of the resulting impressions were measured using a laser probe three-dimensional measuring instrument.

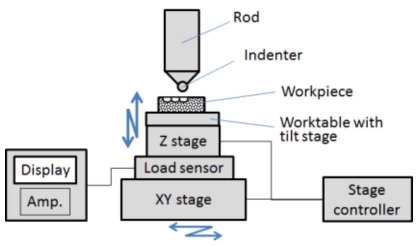

Figure 1. Schematic of our newly developed indentation machine.

3. Experiment on wrought pure aluminum

We performed an experiment using wrought pure aluminum plates as workpieces. Figure 2 shows the experimentally obtained cross-sectional profiles of impressions for indentation loads ranging from 10 to 70 N. As shown in Fig. 2, the depth of the impressions increases with increasing indentation load, and the depth of their centres is almost proportional to the indentation load. The outer edges of the impressions are found to increasingly pile up with increasing indentation load. Such pileups cause shape errors in a lens array mold when the mold is produced by the repetition of a single indentation. Thus, we discuss how to control the height of pileups in the next section.

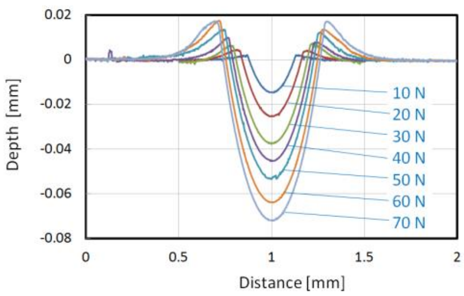

Figure 2. Experimental results for wrought pure aluminum showing cross-sectional profiles of impressions for various indentation loads.

4. Experiment on porous sintered pure aluminum

The pileups shown in Fig. 2 resulted from the flow of material towards the workpiece surface from the impression formed by the indentation. We assume that such flow does not occur in a porous metal. Thus, we carried out the following experiments using porous sintered pure aluminum as the workpiece material.

We manufactured pure aluminium disks by sintering using aluminum powder with an average grain size of 15 µm. The sintering process was conducted so that the disks as above were porous. The resulting disks had a porosity of 9%. Then, one side of each sintered disk, which was used for indentation experiments, was polished with a polishing paper having an average grain size of approximately 10 µm. The indentation experiments were performed with indentation loads ranging from 10 to 70 N.

Figure 3 shows superimposed cross-sectional profiles of the resulting impressions for various indentation loads, illustrating that pileup does not occur at the outer edges of the impressions. Figure 4 shows superimposed profiles of the indenter and the impression for an indentation load of 70 N. These profiles are superimposed such that their bottoms overlap. Figure 4 reveals that the outer edges of the impression slightly sink to below the surface level.

We evaluated the transfer property of the indenter profile to the impression profile by calculating the deviation between the two profiles. The deviation of the impression profile from the indenter profile is referred to as the shape error in this paper. Figure 5 shows examples of the shape errors for indentation loads of 10, 40, and 70 N. In Fig. 5, every curve drops sharply at both ends. This corresponds to the sinking at the outer edges of the impression shown in Fig. 4. As shown in Fig. 5, we obtained impressions with shape errors ranging from 1 to 2 µm in the area excluding the outer edges. Such shape errors of 1 to 2 µm may be due to elastic recovery after the removal of the load applied by the indenter or due to the elastic deformation of the indenter. To achieve impressions, i.e., lens elements, with higher shape accuracy, one method is to correction the shape of the indenter. Since the shape errors are axially symmetric, such correction would not be difficult.

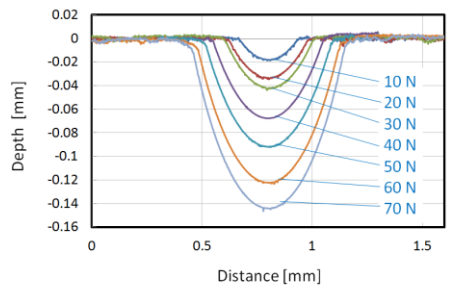

Figure 3. Experimental results for porous sintered pure aluminum showing cross-sectional profiles of impressions for various indentation loads.

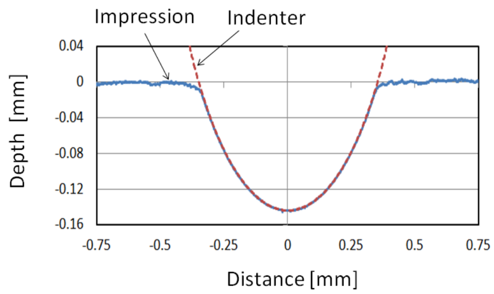

Figure 4. Cross sectional profiles of indenter and impression on a porous sintered pure aluminum disk for an indentation load of 70 N.

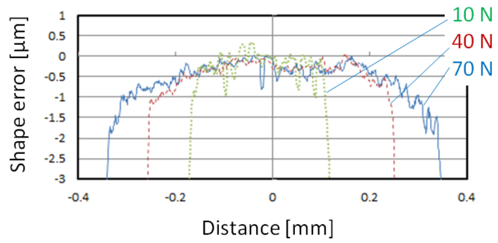

Figure 5. Cross-sectional profiles of shape errors of impressions on a porous sintered pure aluminum disk for various indentation loads.

5. Conclusions

We proposed a method for forming lens elements on a mold surface by indentation to efficiently produce lens array molds. In this method, a flat sintered metal plate is used as a workpiece. Repeating the indentation process enables a number of lens elements to be rapidly produced on the mold surface. In this method, if the metal plate is too soft for the mold, the electroforming of the indented surface is performed to produce a hard surface. Aspherical shapes can be formed if an indenter with an aspherical profile is used.

In this study, to fundamentally investigate the characteristics of our method, we formed single impressions, i.e., lens elements, on a surface with various indentation loads using our newly developed machine. The experimental results demonstrated that impressions with spherical profiles were successfully produced by our method. The depth of impressions with a curvature radius of 0.5 mm was varied by controlling the indentation load. The resulting single impressions had shape errors of approximately 1 to 2 µm for a depth of up to approximately 140 µm.

References

[1] Forest C R, Saez M A and Hunter I W 2007 Appl. Opt. 46, 36, 8668-8673.

[2] Kobayashi Y, Sakamoto H, Iwahara M and Shimizu S 2011 Proc. Abrasive Technology Conference 281-282 (in Japanese).

[3] Yan J, Horikoshi A and Kuriyagawa T 2009 Proc. JSPE Autumn Meeting, 63-64 (in Japanese).