Polishing Techniques of Stainless Steel Molding Die for the Slumping Method of Glass Optical Components

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Abstract: In recent years, high precision geometric shape, surface roughness, and cost reduction are required for large glass component molding processes. In this research, the polishing process of stainless steel molding dies used to form thin glass components is investigated. The surface roughness of the polished stainless steel molding die surface is below $R_z = 200$ nm (P-V) at 15 h polishing with 0.5 % alumina polishing liquid. In the case of polishing process with only the weight of molding die and a polishing pressure of 0.5 kPa, polishing times are approximately 60 h and 20 h, respectively. Final surface roughness polished stainless steel molding die surface with pressure of 0.5 kPa is $R_z = 7$ nm (P-V), $rms = 1.6$ nm and $Ra = 1.4$ nm. In a thin glass component manufacturing method, “slumping method”, surface roughness before glass forming is $rms = 0.7$ nm and $Ra = 0.6$ nm, and after is $rms = 0.7$ nm and $Ra = 0.6$ nm. Therefore, there were no observable changes their surface roughness.

Key words: Molding die polishing, stainless steel, glass forming, surface roughness, slumping method.

1. Introduction

The high precision technology for small optical components has been already established in optical component manufacturing fields. On the other hand, in recent years, high precision geometric shapes, surface roughness, and cost reduction are required for large optical component molding processes [1, 2]. As an example, the manufacturing technology of the large-sized mold die with 300 mm diameter and 400 mm height is given [3-5]. This molding die is machined by an ultra-precision diamond turning with a large size ultra-precision lathe [6-8], and it is completed by a hand polishing process to improve a surface roughness of turned surfaces. Therefore, it is thought that it is difficult to keep high shape accuracy, though surface roughness can be improved in this method.

For economical manufacturing, we have to consider the reduction of complex processes, manufacturing time, and material cost. Especially, these are important in the aero space field that uses special optical components [9].

In this research, the polishing process of stainless steel molding dies is used to form thin glass components and the glass forming process by “slumping method” is investigated to make simple and reasonable glass forming technologies.

2. Glass Forming Method “Slumping Method”

Fig. 1 shows the thin glass forming process as executed in this research. In recent manufacturing fields, a large scale glass optical component manufacturing process is difficult, because of the brittleness of thin glass base material. Though, the method with high precision molding dies is executed in large glass forming processes. In this research, to form thin glass component shapes, the “slumping method” that uses thermal deformation with molding dies is proposed.

The forming processes are as follows:
(a) High precision molding dies are machined;
(b) Set up a thin glass plate on molding dies;
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(c) Heat up to glass deformation temperature [3], then glass plate transforms along a molding die shape;
(d) Separate formed glass plates from molding dies.

In this process, it was assumed that surface properties as surface roughness and some shape of molding dies are copied to formed glass surfaces. Therefore, to obtain high precision properties in glass surfaces, molding dies that have a high precision have to be manufactured.

3. Experiments Procedure

The polishing experiments are executed by a bench type polishing machine for stainless steel SUS304 in JIS die sample of 50 mm in diameter and 10 mm thickness. Main experimental conditions are summarized in Table 1. In the polishing process, 0.5% alumina polishing liquid is supplied on a polishing pad. To compare polishing times, polishing pressure of 0 kPa and 0.5 kPa are loaded for two workpieces. The polishing pressure of 0 kPa means that it is only the weight of the molding die. Surface roughnesses of SUS304 molding die surface and glass surface are measured by a surface interferometer (NewView 7100, zygo) and a surface roughness measurement instrument (SJ-201, Mitutoyo).

In this investigation, a thin glass plate of 0.2 mm thickness and 20 × 20 mm² sizes is used as forming glass materials. Fig. 2 shows the glass plate surface properties of before forming. The surface roughness of thin glass plate before forming is $rms = 0.7$ nm and $Ra = 0.6$ nm. From this result, it is found that a glass plate surface without any working has a very smooth surface that roughness is below 10 nm.

4. The Influence of Molding Die Surface Roughness for Formed Glass Surface

To examine an influence of copying ability that a molding die surface roughness is copied to a formed glass plate surface, a glass forming method shown in Fig.1 is experimented with a molding die and sample glass plate. Fig. 3 shows a comparison of glass plates surface of before and after forming with slumping method. Originally, glasses used in this experiment is colorless and transparent. Therefore, there is nothing on a surface of base glass plate surface as shown in

| Table 1 | Experimental conditions. |
|---------|--------------------------|
| Polishing machine | Bench type polishing machine (MA-200, Musashino denshi Co., Ltd) |
| Workpiece materials | Stainless steel SUS304 in JIS |
| Polishing pad | Suede type |
| Polishing liquid | 0.5% alumina polishing liquid |
| Polishing pressure | 0 kPa and 0.5 kPa |
| Measuring instrument | 3D optical surface profiler (NewView 7100, zygo) |
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Fig. 3 Microphotographs of glass plate surfaces in before and after forming.

(a) Before forming  (b) After forming

Fig. 3a. On the other hand, lines of crosswise direction which is 0.4 mm interval is observed on the formed glass plate surface as shown in Fig. 3b. And it is found that a density of line is not constant on surface.

In this examine, the molding die with comparatively rough surface was used to show a copying ability clearly. Fig. 4 shows a microphotograph of SUS304 molding die surface finished by using lathe turning. On a molding die surface, cutting grooves are carved at intervals of 0.4 mm is observed as shown in Fig. 4. From these results, it is thought that cutting grooves are copied to formed glass surface, because line intervals of crosswise direction on a formed glass plate surface shown in Fig. 3b is similar to cutting groove intervals of molding die surface.

Therefore, to confirm that result, it measured surface roughness by a surface roughness measuring machine. To measure a wide length of 4 mm, a surface roughness measurement instrument (SJ-201, Mitutoyo) is used. Fig. 5 shows a surface roughness of molding die surface. The feed rate set at lathe turning is 0.4 mm/rev, roughness of corresponding 0.4 mm to it can be confirmed on the die surface profile as shown in Fig. 5. A surface roughness of formed glass plate surface shown in Fig. 3b is $R_z = 0.74 \, \mu m$ as shown in Fig. 6. In the left side area of measurement length, a surface shape change is comparatively small. On the other hand, in the right side area of 2-4 mm, it is confirmed that a glass surface shape after forming is similar to molding die surface shape. By these results, it is found that a molding die surface shape is transcribed on a formed glass surface. However, that transcript does not occur to all area and is not constant as shown in Fig. 6. In this result, a surface roughness of molding die is copied to form glass surface, and molding die surface must be smooth.

5. Polishing Process for Stainless Steel SUS304 Molding Die

Fig. 7 shows the relationship between surface roughness $R_z$ and polishing time in a SUS304 molding die polishing. A base workpiece surface is a cutting surface with a roughness of approximately $R_z = 3,000$ nm (P-V). In the case of polishing with polishing pressure of 0 kPa, a surface roughness of 20 h polishing is 1,000 nm. Afterwards, that surface roughness decreases gradually, it is below 100 nm at 60 h polishing. On the other hand, a surface roughness of polished SUS304 surface with 0.5 kPa decreases.
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Fig. 7 Relationship between surface roughness $R_z$ and polishing time in a SUS304 molding die polishing.

(0.5% alumina polishing liquid, $N = 100$ rpm, $l = 50$ ml/h)

rapidly. At only 7 h, it is below 1,000 nm, a roughness of below 100 nm was obtained at about 30% polishing time of a case of 0 kPa.

Fig. 8 shows a polished SUS304 molding die surface with polishing pressure 0.5 kPa and 20 h polishing. It can be confirmed that the lattice pattern is reflected on that surface.

A result of surface roughness measured with a surface roughness measurement instrument is shown in Fig. 7. Generally, a molding die surface is measured by optical surface profilers. Then the surface roughness shown in Fig. 8 was measured by 3D optical surface profilers.

Fig. 9 shows a surface roughness of a polished surface shown in Fig. 8 measurement result that is measured by NewView 7100. Surface roughnesses are $R_z = 7$ nm, $rms = 1.6$ nm and $Ra = 1.4$ nm, respectively. By this result, it is described that a smooth polishing surface which is similar to glass surface roughness with below 10 nm as shown in Fig. 2, is obtained by a polishing process with polishing pressure of 0.5 kPa and polishing time of 20 h.

6. Glass Forming Process with Ultra Precision Molding Die

The “slumping method” shown in Fig. 1 was examined to know the influence of molding die surface on a formed glass surface. In this investigation, a thin glass plate of 0.2 mm thickness and $20 \times 20$ mm$^2$ sizes is used. And it was heated at 640 °C and 685 °C to form glass component shapes in an electric furnace [10, 11].

Fig. 10 shows the change of glass surface properties of after forming. The surface roughness of thin glass plate before forming is $rms = 0.7$ nm and $Ra = 0.6$ nm as shown in Fig. 2. On the other hand, the surface roughness of after forming is $rms = 0.7$ nm and

Fig. 9 Surface roughness of polished SUS304 molding die surface.

(0.5% alumina polishing liquid, $N = 100$ rpm, $l = 50$ ml/h)
The surface roughness of glass plate surface after forming.
(NHK120-H, 70 min at 640 °C, 60 min at 685 °C)

Ra = 0.6 nm as shown in Fig. 10. From these results, both surface properties are similar, therefore, it is found that the influence of a molding die surface which surface roughness is below 10 nm is not observed on a formed glass surface in this method.

7. Conclusions

In this research, the polishing process of stainless steel molding dies is used to form thin glass components and the glass forming process by "slumping method" has been considered. The main conclusions are as follows:

(1) A surface roughness of molding die is copied to a formed glass surface. Therefore, molding die surfaces must be manufactured to smooth surface with no influence to formed glass surfaces.

(2) By applying polishing pressure, the polishing time is reduced to below half the time required when polishing without pressure.

(3) Final surface roughness of polished stainless steel molding die surface with polishing pressure of 0.5 kPa are Rz = 7 nm, rms = 1.6 nm and Ra = 1.4 nm, respectively, is achieved.

(4) In slumping method with polished stainless steel molding dies, the roughness of formed glass surface remains the same as that before forming.

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