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Stainless steel molding die polishing techniques for the production 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 *Rz*=200 nm (P-V) at 15 hours 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 hours and 20 hours respectively. Final surface roughness polished stainless steel molding die surface with pressure of 0.5 kPa is *Rz*=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.

Keywords: molding die polishing, glass forming, glass optical components, 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]. 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.

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"

Figure 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 a 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 shapes, the "slumping method" that uses thermal deformation with molding dies is proposed.

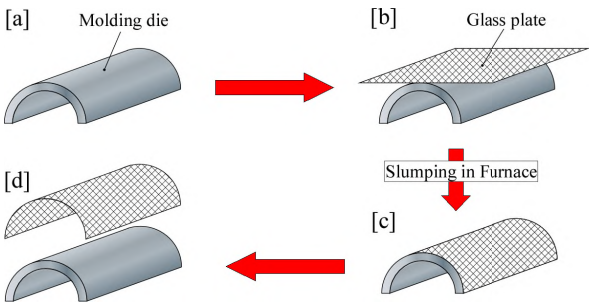


Figure 1. Method of glass optical components in slumping method

The forming processes are as follows:

[a] High precision molding dies are machined.
[b] Set up a thin glass plate on molding dies.
[c] Heat up to glass deformation temperature [3], then glass plate transforms along the molding die shape.
[d] Separate the formed glass materials from molding dies.

In this process, it was confirmed that surface properties as surface roughness and some shape of molding dies are copied to formed glass surfaces [3]. Therefore, to obtain high precision properties in glass surfaces, molding dies that have a high precision have to be manufactured.

3. Polishing process for SUS304 molding die

3.1. 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 2 workpieces. The polishing pressure of 0 kPa means that it is only the weight of the molding die. Surface roughness of SUS304 molding die surface is measured by a surface interferometer (NewView 7100, zygo) and a surface roughness measurement instrument (SJ-201, Mitutoyo).

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]

3.2. Evaluation of polished SUS304 surface and that process

Figure 2 shows the relationship between surface roughness *Rz* and polishing time in a SUS304 molding die polishing. A

base workpiece surface is a cutting surface that surface roughness is approximately *Rz*=3,000 nm (P-V). In the case of polishing with polishing pressure of 0 kPa, a surface roughness of 20 hrs polishing is 1,000 nm. Afterwards, that surface roughness decreases gradually, it is below 100 nm at 60 hrs polishing. On the other hand, a surface roughness of polished SUS304 surface with 0.5 kPa decreases rapidly. At only 7 hrs, it is below 1,000 nm, a surface rougheness of below 100 nm was obtained at about 30 % polishing time of a case of 0 kPa.

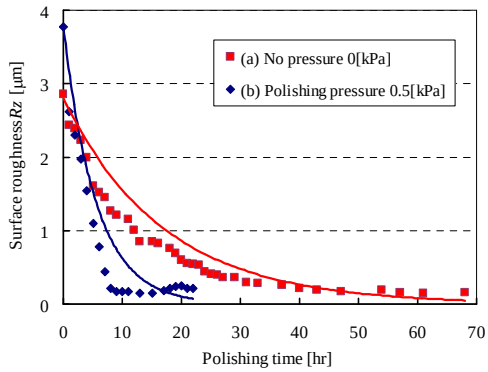


Figure 2. Relationship between surface roughness *Rz* and polishing time in a SUS304 molding die polishing
[0.5% - Alumina polishing liquid, *N*=100 rpm, *l*=50 ml/h]

Figure 3 shows a polished SUS304 molding die surface with polishing pressure 0.5 kPa and 20 hrs polishing. It can be confirmed that the lattice pattern is reflected on that surface.

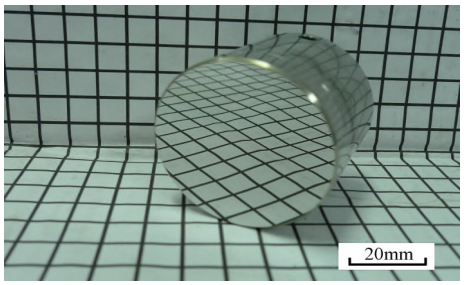


Figure 3. Polished SUS304 molding die surface after 20 hours polishing with polishing pressure of 0.5 kPa

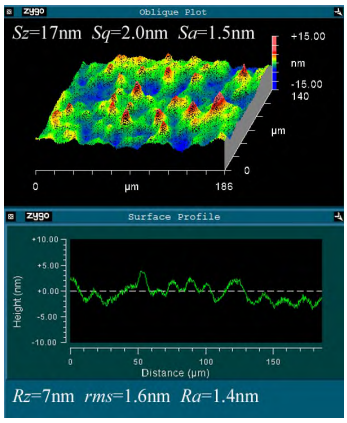


Figure 4. Surface roughness of polished SUS304 molding die surface
[0.5% - Alumina polishing liquid, *N*=100 rpm, *l*=50 ml/h]

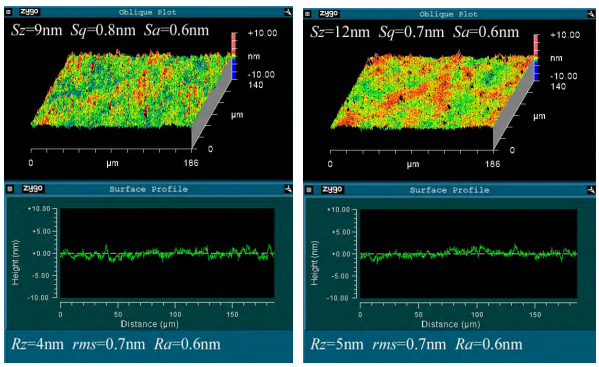
A result of surface roughness measured with a surface roughness measurement instrument is shown in Figure 2. So it is guessed that a limit of measurement is about 100 nm. Then the surface roughness shown in Figure 3 was measured by a surface interferometer.

Figure 4 shows a surface roughness of a polished surface shown in Figure 3 measurement result that is measured by NewView 7100. Surface roughnesses are *Rz*=7 nm, *rms*=1.6 nm and *Ra*=1.4 nm respectively. By this results, it is described that a smooth polishing surface is obtained by a polishing process with polishing pressure of 0.5 kPa and polishing time of 20hrs.

4. Glass forming process with ultra precision molding die

The "Slumping method" shown in Figure 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 mm x 20 mm sizes is used. And it was heated at 640 and 685 degrees in an electric furnace.

Figure 5 shows the change of glass surface properties of before and after forming. The surface roughness of thin glass plate before forming is *rms*=0.7 nm and *Ra*=0.6 nm as shown in Figure 5(a). On the other hand, the surface roughness of after forming is *rms*=0.7 nm and *Ra*=0.6 nm as shown in Figure 5(b). From these results, both surface properties are similar, so the influence of molding die surface on a formed glass surface was not observed in this method.



(a) Before forming (b) After forming

Figure 5. Comparison of glass plate surface before and after forming
[NHK120-H, 70 min at 640 degrees, 60 min at 685 degrees]

5. Conclusion

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] The polishing time of stainless steed molding die surface polishing with applying polishing pressure is decreased to below half compared to the polishing pressure.

[2] Final surface roughness of polished stainless steed 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.

[3] In slumping method with polished stainless steed molding dies, the influence of molding die surface on a formed glass surface was so low as to be immeasurable.

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