Fabricating freeform molding dies from materials such as CVD SiC with mirror surface finish is very challenging. A novel Shape Adaptive Grinding (SAG) method capable of finishing freeform molding dies with surface roughness below 1nm Ra is presented in this paper. The long lifetime of the grinding tools, up to 10 hours, is also investigated.

1. Introduction

Manufacturing of optical components by replication from molding dies has been increasingly adopted by the consumer electronics industry, where mass production at low cost is paramount. Typical manufacture methods include press molding of glass lenses from steel and carbide die inserts. The production of small molds by ultra-precision grinding [1] and polishing [2] has been well documented. However, the required apparatus and tooling remains costly, time consuming, and difficult to scale up to large mold sizes (above 100mm).

In this paper, a novel method called Shape Adaptive Grinding (SAG) [3] is presented that may significantly reduce manufacture costs and time in the production of dies inserts for glass optics molding. Starting from a very rough machining state > 1 μm Ra, such as milling or CVD coating, this method can efficiently and predictably deliver surface roughness < 1 nm Ra without any need for periodical tool dressing. General tool compliance with curved surfaces also means that it can be used to process most freeform shapes, either convex or concave. The overall process chain is summarized in Fig. 1: the freeform shape is milled into graphite, a CVD SiC coating deposited, and finally ground to optical surface finish. Potential applications include aspheric and freeform optics, optical molding dies, as well as curved screens for consumer devices such as cellphones and tablets.

2. Experimental Procedure

The basic principle of the SAG tool consists of maintaining general compliance between the tool and freeform surface over a sub-aperture contact area of the workpiece, as shown in Fig. 2 (left). But at the same time, hard contact is achieved at relatively smaller scale by rigid pellets, inside which diamonds are embedded, covering the surface of the elastic tool. In this way, effective grinding can take place (rather than polishing which would result from a soft contact). Actual tool samples with radius of curvature R5, R10 and R20 mm are shown in Fig. 2 (right).

A series of process characterization experiments were carried out on CVD silicon carbide. The samples were 100 mm diameter graphite pucks coated with 100um thick CVD silicon carbide, prepared in industry. The range of parameters included usage of resin and nickel for the pellet material, diamond grit sizes ranging from 3 to 40 µm diameter, SAG tool radius ranging from 10 to 40 mm, and machine feed rates ranging from 10 to 1000 mm/min. At regular interval between the grinding experiments, the tools were inspected with a confocal laser microscope, to monitor the evolution of the diamond abrasives (see Fig. 3).

Fig. 1. Process chain to produce molding dies with optical quality surfaces (for optical assembly or replication).

Fig. 2. Shape Adaptive Grinding (left), Tool samples (right).

Fig. 3. Grinding tool inspection on confocal laser microscope.
3. Experimental Results and Discussion

Grinding modes were characterized with a laser confocal microscope at 100x magnification. The micrographs revealed full transition fracture to ductile mode, as shown in Fig. 4. Micrographs for the 9 µm diamond abrasives bound in either nickel or resin were identical. Likewise, air pressure did not have much influence on the number of fracture pits observed in the micrographs. Diamond grain size was thus found to be the main factor for fracture to ductile mode transition.

4. Conclusions

An innovative shape adaptive grinding (SAG) tool was presented, which can be used for finishing substrates coated with silicon carbide by chemical vapor deposition. The characteristics of this novel grinding process are as follow:

1. Productivity is high since the diamond abrasives remain stable for more than 10 hours (re-dressing cycles are not necessary), with high removal rates up to 100 mm³/min.
2. Although the tool and CNC machine have very low stiffness, purely ductile mode grinding can be achieved at low diamond grain sizes (below 9 µm).
3. Starting from a rough CVD condition above 1 µm Ra, final surface roughness below 0.4 nm Ra can be achieved.

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References