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Shape Adaptive Grinding (SAG) of Freeform Ceramic Molding Dies

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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. The production of small molds by ultra-precision grinding and polishing 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). A novel method called Shape Adaptive Grinding (SAG) is presented that may significantly reduce manufacture costs and time in the production of ceramic molding dies.

2. PRINCIPLE OF SAG

The basic principle of the SAG tool is shown in Fig. 1. It consists of maintaining general compliance between the tool and a freeform surface over a sub-aperture contact area of the workpiece. 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).

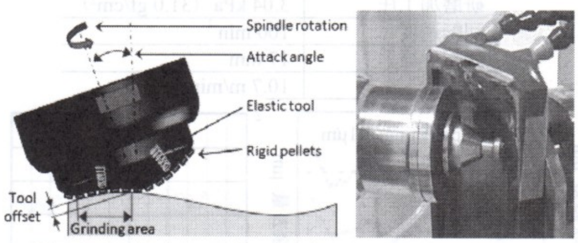
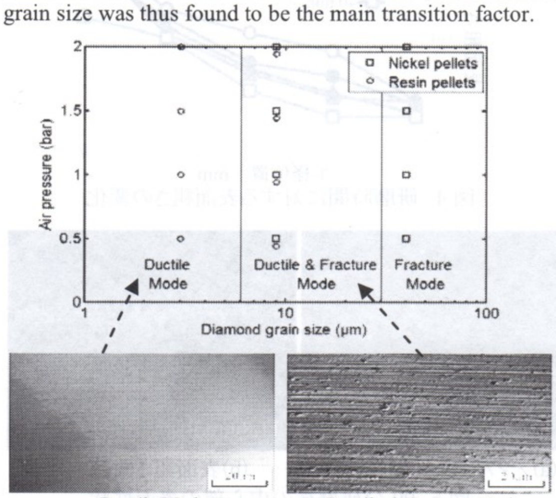


Fig. 1 Principle of Shape Adaptive Grinding (SAG)

3. PROCESS CHARACTERIZATION

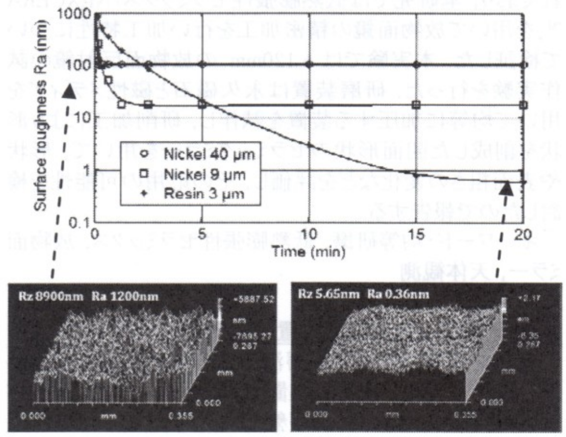
Grinding modes were characterized with a laser confocal microscope at 100x magnification, as shown in Fig. 2. Full transition from fracture to ductile mode was observed. Micrographs for 9μm diamond grains bound in either nickel or resin were identical. Likewise, air pressure did not have much influence on the number of fracture pits. Diamond grain size was thus found to be the main transition factor.



Ductile Mode Ductile & Fracture Mode

Fig. 2 Characterization of grinding modes

Starting from a micro-roughness above 1000nm Ra, such as CVD SiC coating, this method can efficiently and predictably deliver roughness below 1nm Ra, as shown in Fig. 3. The tools showed stable removal rate over periods exceeding 10 hours under typical operating conditions.



CVD SiC coating Ground with 3um diamonds & resin

Fig. 3 Characterization of surface texture

In conventional grinding, there exists a direct relationship between removal rate and the achievable surface roughness. The dashed line in Fig. 4 shows the typical path followed when going from brittle to ductile grinding regime. The SAG tool offers an alternative to this traditional path by delivering low surface roughness down to less than 0.4 nm Ra while maintaining very high removal rates (up-to 2 orders of magnitude higher than conventional methods).

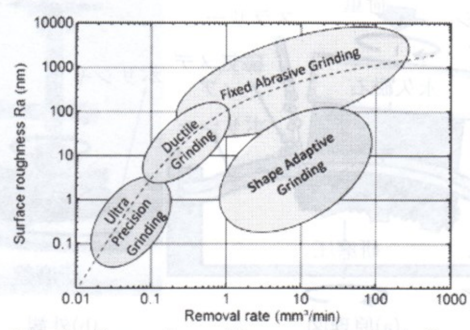


Fig. 4 Comparison with conventional grinding

4. CONCLUSION

In summary, the characteristics of the novel Shape Adaptive Grinding (SAG) 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 $100mm^3$/min.
2. Although the tool and CNC machine have very low stiffness, purely ductile mode grinding can be achieved at low diamond grain sizes.
3. Starting from a rough CVD condition above 1μm Ra, final micro-roughness below 0.4nm Ra can be achieved.
4. General tool compliance with curved surfaces means that it can be used to process most freeform shapes.