Shape Adaptive Grinding of Optical Surfaces for Scientific Applications and Consumer Products

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Abstract: Shape Adaptive Grinding (SAG) is a new process capable of producing optical mirror quality surfaces (Ra <0.5nm) on CVD silicon carbide coatings. The methodology and capability of the SAG process are presented in this paper.

OCIS codes: (120.4610) Optical fabrication; (220.1920) Diamond machining.

1. Introduction

Chemical vapor deposition (CVD), infiltration (CVI), and reaction (CVR) can be used to deposit silicon carbide (SiC) cladding on graphite [1]. The cost of such technologies has been steadily decreasing over the past few years, making them increasingly ubiquitous. For example, high speed 5-axis milling can be used to machine complex shapes into the graphite substrate [2], after which a CVD coating is deposited to produce a highly resistant surface (see Fig. 1). The resulting surface can be used as a molding die for replication by pressing/slumping glass under high temperature (above 800 °C). This methodology finds application in consumer products with optical quality components, such as smart-phones and digital cameras. In other cases, the shape itself can be pocketed during the milling stage to produce light-weight optical components. Such components find application in space telescope missions, as well as ground based telescopes with large mirror area.

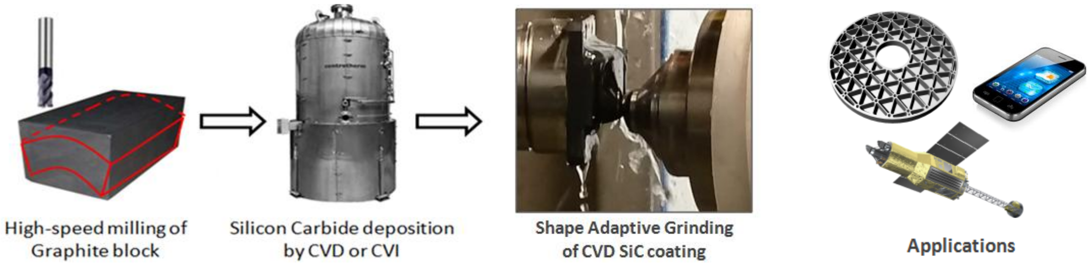

Fig. 1. Process chain to produce silicon carbide components with optical quality surfaces (for optical assembly or replication). Some applications shown on the right: light-weighted mirrors, x-ray space telescopes, consumer products (smartphones, cameras).

2. Shape Adaptive Grinding

The CVD deposition process tends to produce grain like structured surfaces that become rougher as the deposition depth increases. For example, Fig. 2 (left) shows a confocal laser microscope observation (100x objective) of a graphite surface coated with 100um thick CVD silicon carbide. Such surface is very rough (usually around 1.0µm Ra), so it is necessary to machine the CVD surface by grinding or polishing [3]. But in the case of freeform surfaces, it is difficult to obtain a smooth surface while retaining the 5-axis milled shape accuracy. To address this issue, an innovative Shape Adaptive Grinding (SAG) tool has been developed that can finish CVD silicon carbide surfaces down to optical mirror quality (less than 0.5nm Ra) while retaining or improving the global form accuracy [4].

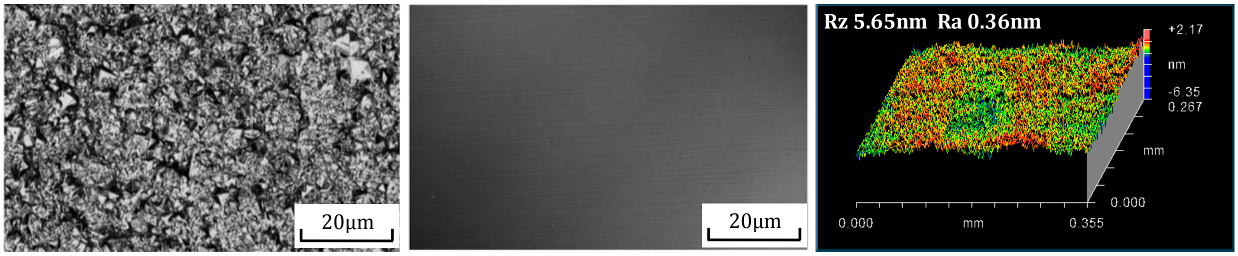

Fig. 2. Micrographs at 100x of SiC surface after CVD coating (left) and SAG machining (center). Final micro-roughness at 50x (right) [4].

The basic principle of the shape adaptive grinding 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. 3 (left). But at the same time, hard contact is achieved at relatively smaller scale by rigid pellets loaded with diamonds that cover the surface of the elastic tool, such that effective grinding can take place (rather than a soft contact resulting in polishing).

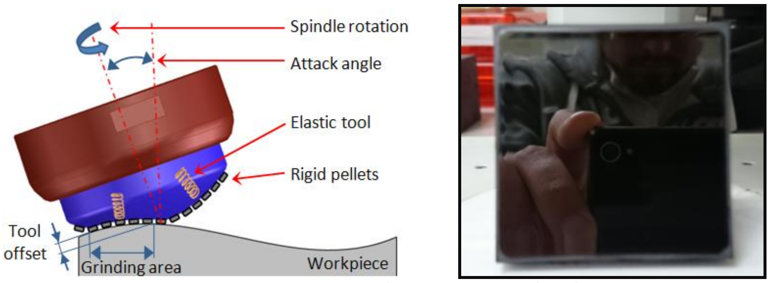

Fig. 3. Principle of Shape Adaptive Grinding (SAG) tool [4] (left) and example of surface with optical mirror finish (right).

3. Grinding Force during SAG Operation

The grinding force was measured with a dynamometer mounted inside the CNC machine used to operate the SAG process (see Fig. 4, left). Typical grinding parameters were used for this experiment, as follows: spindle rotation speed 1500rpm, pressure inside the elastic tool 2.0bar, offsetting of the tool against the workpiece 0.35mm, and grinding tool feed 150mm/min. A variety of pellets and abrasive grits were used in the experiments, including: nickel pellets (40 and 9µm diamonds) and resin pellet (9 and 3µm diamonds).

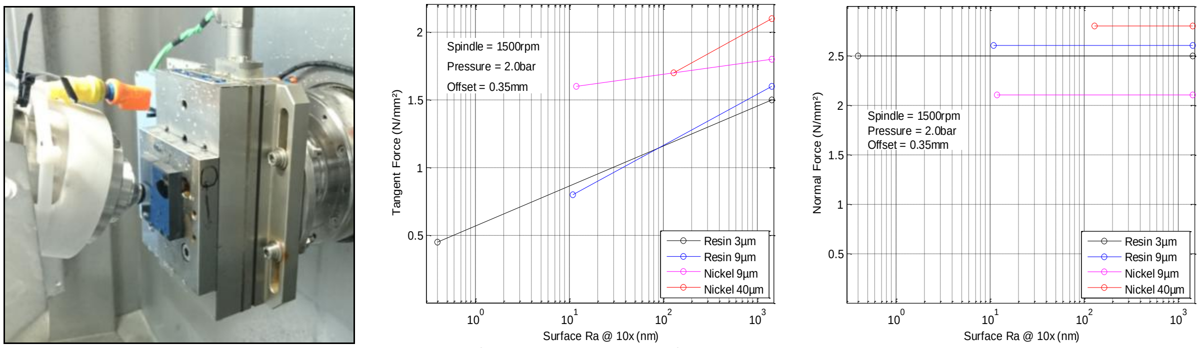

Fig. 4. Experimental setup with dynamometer (left), measured grinding force in the tangential (center) and normal (right) directions.

The tangential and normal forces were recorded for each pellet, as well as the surface roughness before and after each experiment. The resulting data is shown in Fig. 4 (center and right). It was found that the normal force remains constant no matter what the surface condition, while the tangential force increases as a logarithmic function of the surface roughness. This result indicates that in-process evaluation of the surface condition (through monitoring of the ratio between tangential and normal force) is possible. Such in-process monitoring is very desirable in the case of high volume manufacturing of optical quality components used in consumer products.

4. Conclusions

SAG is a novel fabrication method that can achieve optical quality (below 0.5nm Ra) on rough CVD silicon carbide surfaces. In-process assessment of the surface condition is possible, by monitoring the ratio between tangential and normal grinding forces. This method thus promises high productivity and lower costs in optical fabrication.

5. References

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