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Precision grinding of spherical lenses with engineered grinding wheels

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Abstract
This paper introduces the grinding performance of a new spherically segmented tool with a radius of 37.5 mm and a grain size of d_G = 301 µm when grinding spherical lenses from BK7 and Zerodur. In order to get an acceptable concentricity for ultra-precision grinding with coarse grained tools, a thermo-chemical dressing process recently established at Laboratory for Precision Machining has been carried out. For the subsequently performed grinding experiments, cutting speed and depth of cut were varied. Throughout the experiments, the wear of the tool was investigated, regarding morphology of individual grains before and after the grinding process by a confocal laser scanning microscope. To evaluate the performance of the new grinding tool, the surface roughness of the ground lenses has been investigated.

Ultra-precision, grinding, optical glass, coarse grains

1. Introduction

For the manufacturing of optical components for automotive, communication or semiconductor industry, ultra-precision grinding is the process of choice for the finishing of optical surfaces. Conventionally, fine-grained diamond tools with soft bondings are employed for grinding [1]. The disadvantage of these tools is the decreasing form accuracy and surface quality, caused by progressing tool wear. Therefore, continuous or periodical dressing is necessary, however, dressing is cost-intensive and raises auxiliary process time.
For this reason, the application of coarse grained diamond tools for precision grinding has been developed recently [2, 3, 4]. In the preliminary work, the tools exhibited a rectangular profile. In this work, the performance of a new spherically shaped tool is investigated by grinding of spherical lenses.

2. Dressing of the grinding tool

The grinding experiments were performed with a new single-layered coarse grained spherically segmented diamond grinding wheel (radius = 37.5 mm, sketch in Figure 1) with a grain size of d_G = 301 µm and electroplated bonding. In order to achieve a material removal mainly in the ductile regime, the tool was dressed by two consecutive dressing techniques before grinding. Due to the time-consuming abrasive dressing process for coarse grained diamond wheels, first a thermo-chemical profiling, based on dynamic friction polishing, was performed for rough dressing. The resulting run-out error was determined to 25 µm., which needed to be decreased. Thus, a consecutive abrasive fine-dressing with a rotating multigrain diamond dresser with a grain size of d_G = 91 µm was performed, leading to a run-out error of 10 µm.

3. Experimental procedure

The target of the experiments was to investigate the process window for precision grinding spherical lenses with coarse grained diamond wheels, regarding surface roughness and tool wear. All grinding experiments were carried out on a five-axis ultra-precision grinding machine. Figure 1 shows the experimental set-up and the grinding kinematics. The spherical shape (radius = 200 mm) of the lenses was generated on the specimens (diameter = 30 mm) by cross-grinding. To observe the wear of the flattened abrasive grains, the height of the grains was measured by confocal laser scanning microscopy after every grinding experiment. The surface roughness of the ground surfaces was investigated by white-light interferometry.

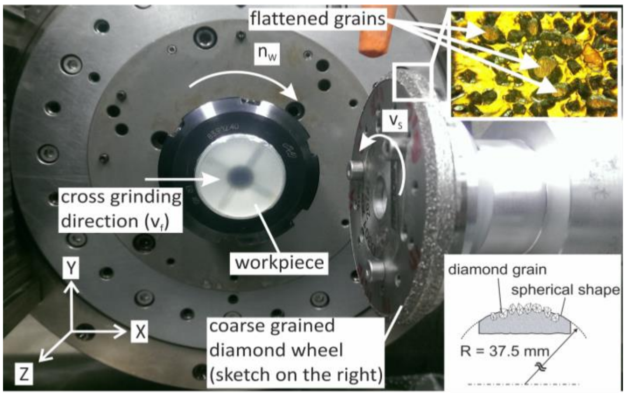

Figure 1. Experimental set-up

Table 1 shows the grinding parameters which were chosen for grinding both materials, BK7 and Zerodur. The circumferential speed of the grinding wheel was 30 m/s and the feedrate 3 mm/min. At first, a rough grinding process with a depth of cut of 20 µm generated the spherical shape on the cylindrical workpieces. Subsequently, a finishing process with a

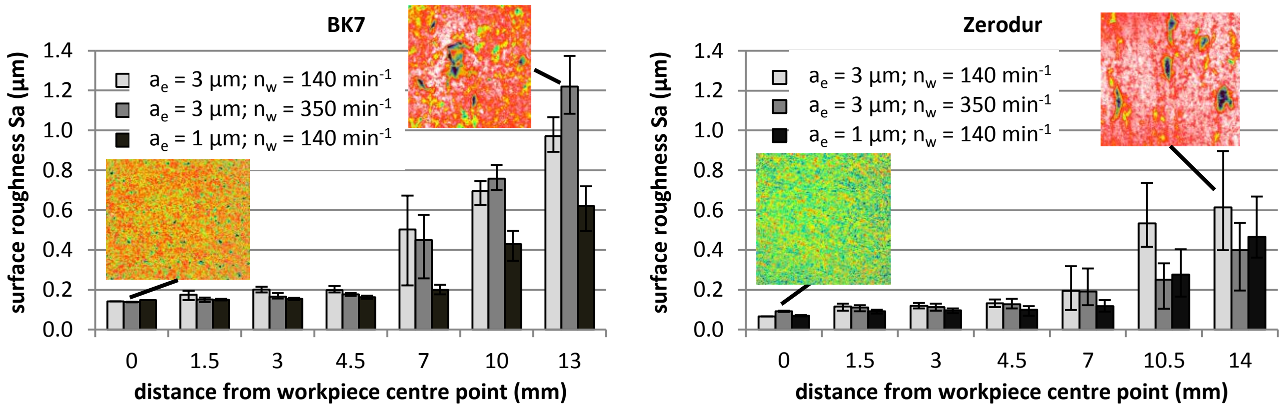

Figure 2. Roughness of ground surfaces on BK7 and Zerodur against the distance from workpiece centre point

depth of cut of 3 and 1 µm generated the final surface which was measured regarding the roughness. Besides, the rotational speed of the workpiece spindle has been varied from 140 to 350 min^{-1}.

Table 1 Grinding parameters

Spherically segmented grinding wheel	d_G = 301, R = 37.5 mm
Kinematic	Cross-grinding, up-hill
Feedrate v_f	3 mm/min
Grinding wheel speed v_s	30 m/s
Workpiece spindle: rotational speed n_w	140 min^{-1}; 350 min^{-1}
Depth of cut a_e	1 µm; 3 µm

4. Results

4.1 Surface roughness

Figure 2 shows the measured surface roughness after the finishing processes with different depths of cut a_e and rotational speeds of the workpiece spindle n_w. As n_w is steady throughout the process, the tangential feed rate is decreasing from the outer diameter of the workpiece to the centre point, where the circumferential speed of the workpiece reaches zero. This leads to changing ratios of wheel speed and tangential feed rate, resulting in increasing surface roughness from workpiece centre to the rim. The lowest values of surface roughness were measured for a_e = 1 µm and n_w = 140 min^{-1}, with a range from 0.14 µm at the centre point to 0.758 µm on the outer diameter of the workpiece for BK7 and 68 nm to 0.398 µm for Zerodur, respectively. Additionally, at a distance from centre point of less than 7 mm, surface roughness below 200 nm is generated for both materials. In general, the surface roughness of BK7 exhibits higher values than Zerodur, which can be explained by the higher brittleness of BK7. Due to that fact, the critical depth of cut is higher for Zerodur, which supports the ductile-regime grinding.

4.2 Wear behaviour

Throughout the experiments, the wear of the tool was investigated regarding the protrusion height of several individual grains after every grinding experiment. Figure 3 shows the measured protrusion height against the removed material volume. Each inspected grain shows a decreasing value for the height with increasing material removal. However, in relation to the initial states, the protrusion height is only decreasing between 4% and 20%, respectively, which means that the diamond grains exhibit a high wear resistance. Additionally, after a material removal rate of 2688 mm^3, the decreasing of height seems to stagnate.
This can be explained by a higher similarity in protrusion height between the grains.

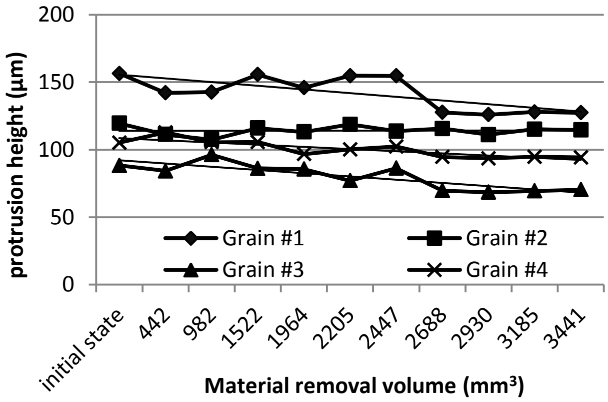

Figure 3. Wear behaviour of different abrasive grains against the removed material volume

5. Summary

In this paper, the grinding performance of a new spherically shaped diamond grinding tool has been investigated by grinding spherical lenses from the materials BK7 and Zerodur. It was shown that the surface roughness strongly depends from the ratio between rotating workpiece and rotating grinding wheel. For both investigated materials, a distance up to 7 mm to the workpiece centre point generated surface roughness below 200 nm. Furthermore, the wear of the tool has been investigated by observing the height of individual diamond grains at increasing material removal. The high potential of the coarse grained diamond tool could be shown, as the decreasing of the height reaches only 4% to 20%. In further investigations, the process window for a beneficial tool application will be determined in detail, especially with respect to the form accuracy of the lenses.

References

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