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Precision grinding of optical glass with laser micro-structured coarse-grained diamond wheels

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ABSTRACT

This paper presents a series of micro-structured coarse-grained diamond wheels for optical glass surface grinding aiming to improve the grinding performance, especially subsurface damage. The 150 μm grit size, single layer electroplated diamond grinding wheels with different interval micro-groove arrays were manufactured by nanosecond pulsed laser, successfully. The influence of micro-structures on surface roughness and subsurface damage was investigated. Compared with conventional coarse-grained diamond wheel, the subsurface damage depth was reduced effectually from 5 to 1.5 μm, although the better surface roughness was not obtained by the micro-structured coarse-grained diamond wheel. In addition, the surface roughness and subsurface damage depth were both reduced with the decreasing interval of micro-groove arrays.

1. Introduction

Precision grinding of optical glasses has extended its applications in aerospace, automotive, semiconductor and communication industry. With the increasing of demand for high accuracy optical glass products, the precision grinding process not only need to meet the requirements of surface roughness in nanometer scale, form deviations in sub-micron level, and subsurface damage depth within micrometer, but also be required to have a high machining efficiency. Fine-grained (grit sizes from several micron down to sub-micron scale) diamond wheels are usually used for finishing of optical glasses with a low surface roughness. However, the wheel loading, high wear rate and periodic conditioning requirement will deteriorate the form accuracy of workpiece at a lower grinding efficiency.

In order to solve the wheel wear problem existed in fine-grained diamond wheels, electroplated nickel mono-layer coarse-grained diamond wheels featuring grit size of 91 μm was alternatively proposed by Brinksmeier et al. (2000) in precision grinding of optical glasses. Koshy et al. (2003) pointed out that the realization of precision grinding with coarse-grained diamond wheels is determined by the distribution of abrasive protrusion height. In order to obtain the coarse-grained diamond wheels with homogeneous grit protrusion, Aurich et al. (2003) optimized the grit pattern of coarse-grained electroplated grinding wheel assisted by kinematic simulation. Zhao et al. (2005) introduced a conditioning method for coarse-grained electroplated diamond wheels using a diamond cup dressing wheel and ELID technique. The applicability of the conditioned coarse-grained grinding wheels was demonstrated by grinding experiments on BK7 glass yielding a surface roughness in the nanometer range. Subsequently, Zhao et al. (2011) tried to apply copper-resin hybrid bonded coarse-grained diamond wheels in ductile grinding of optical glass. The results showed that nanometer scaled surface roughness and higher form accuracy can be obtained at a low wheel wear rate.

The above mentioned investigations indicated that, compared with the fine-grained diamond wheels, precision conditioned coarse-grained diamond wheels could achieve the same nanometer scale roughness, higher form accuracy with a longer wheel life. However, the flat tops of diamond grits created in pre-conditioning process will lead to greater specific grinding normal force as presented by Heinzel and Rickens (2009). Guo et al. (2013) indicated that a serious subsurface damage will be introduced by coarse-grained diamond wheel in optical glass grinding process.

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It has been shown that the micro-structured surface of diamond solid would reduce the normal grinding force as compared with traditional electroplate grinding block provided by Butler-Smith et al. (2013). This is associated with the stability of active cutting elements and the integrity of micro-cutting edges composed by number of micro-structures. Besides, Axinte et al. (2013) indicated that the increased number of cutting edges would also leads to a decrease of specific cutting force in grinding process, which can be obtained by micro-structuring of flat top diamond grits. Therefore, micro-structured diamond surface seems to have the ability to improve grinding performance of coarse-grained diamond wheels and reduce the specific grinding normal force.

Base on the above, this paper presented a kind of micro-structured coarse-grained diamond wheels with micro-groove arrays for optical glass surface grinding aiming to improve the grinding performance, especially subsurface damage. Firstly, the strategy for micro-structuring of coarse-grained diamond wheels was provided. Some micro-structured coarse-grained diamond wheels with different interval parallel micro-groove arrays were manufactured by nanosecond pulsed laser. The morphology of the micro-structured wheels was analyzed by SEM. And then these wheels were properly conditioned by a metal bond diamond dressing wheel with ELID method. Finally, the micro-structured coarse-grained diamond wheels were used in optical glass grinding experiments. The ground surface quality and subsurface damage were characterized by profilometer and SEM, respectively. The influence of micro-structures of wheel surface on surface roughness and subsurface damage depth were investigated.

2. Surface micro-structuring of coarse-grained diamond wheel by laser

Fig. 1 shows the schematic of the micro-structuring operation on coarse-grained diamond wheels' cylindrical surface by laser. The micro-structures composed by parallel micro-groove arrays with various intervals on the diamond wheel can be created by individual setting of the laser scan feed step, showed in this figure. The kinematic parameters of wheel rotation speed and dwell time per laser scan feed step are designed to ensure the whole wheel surface could be micro-structuring. Furthermore, more complex micro-structures can also be machined on wheel surface by adjustment of more parameters such as the laser scan feed direction, wheel rotation direction, laser scan feed rate, and so on.

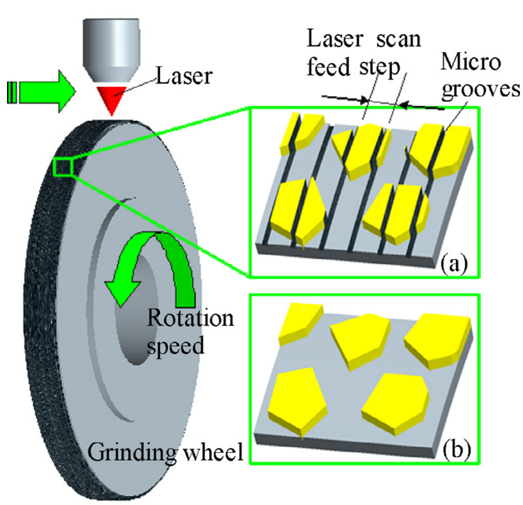

Fig. 1. Schematic view of laser micro-structuring (a) micro-structured coarse-grained diamond wheel (b) conventional coarse-grained diamond wheel.

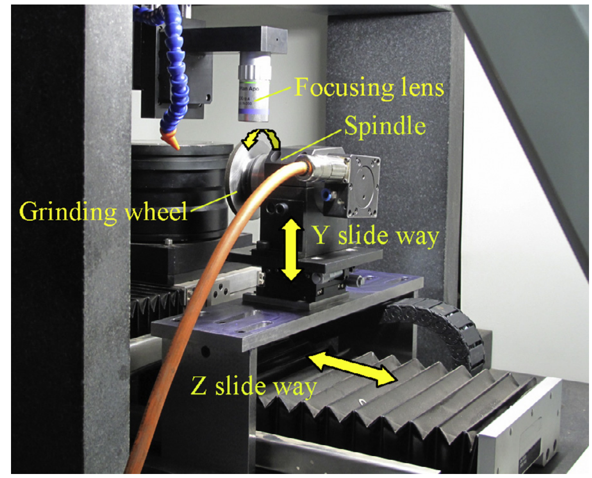

Fig. 2. Experimental setup for coarse-grained diamond grinding wheel structuring.

In this experiment, the 1A1 type single layer electroplated diamond grinding wheels with 150 μm grit size were used. The diameters of these grinding wheels are 85 mm, and the widths are 6 mm. A precision spindle (Dr. Kaiser C58F3) was used to rotate the grinding wheel under laser source. An UV nanosecond pulsed laser with 355 nm wavelength and 1–255 kHz pulse repetition frequency was selected as the laser source to machining micro-groove arrays on coarse-grained diamond wheels. The photo of the experimental setup for coarse-grained diamond grinding wheels structuring is shown in Fig. 2.

Four micro-structured grinding wheels (No. 2–5) with different interval micro-groove arrays were machined by laser. The half peripheral area of No. 2 grinding wheel was structured with 70 μm interval micro grooves. The intervals of No. 3–5 grinding wheel were 30, 90 and 150 μm, respectively. The parameters of micro-structuring are shown in Table 1.

The photo of micro-structured wheels and SEM images of wheel morphology are shown in Fig. 3. On micro-structured surface, the continuous micro-grooves were obtained. The widths of grooves were 10–15 μm. The protruding parts of most diamond grits were cut-through by one or two grooves. The broken diamond grit and falling off of grit was not found. Therefore, the coarse-grained diamond grinding wheels were micro-structured by UV nanosecond pulsed laser, successfully.

3. Grinding experimental setup and procedure

The experiments to evaluate the effects of the micro-structured coarse-grained diamond wheels on the precision grinding of optical glass were conducted on a precision plane grinder from Hangzhou Machine Tool Group Co., Ltd., model "MUGK7120X5". The workpiece material was optical glass BK7. The precision spindle used in laser machining process with micro-structured coarse-grained diamond wheel was fixed on this grinder as grinding spindle. The grinding parameters were 3000 r/min spindle speed, 2 μm depth of grinding and 2 mm/min feed rate. Water-base emulsion was used as a coolant to improve the grinding process. The angle between the grinding feed direction and wheel axial direction was 45°, in order to reduce the ground residual height due to the parallel micro-groove arrays of grinding wheel surface. The experimental setup and the kinematic illustration of the grinding process are shown in Fig. 4.

Before grinding, the ELID assisted conditioning technique with metal-bond diamond truer was used to conditioning these coarse-grained diamond wheels. The truer was assembled on the main spindle of grinder. The grit size of truer is 90 μm and the diameter