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Precision grinding of BK7 glass with coarse-grained diamond grinding wheels

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Abstract
Ultra-precision grinding enables the economical machining of brittle materials. With ductile machining, high surface qualities, low subsurface damage and tight tolerances can be achieved.
Fine-grained grinding wheels are commonly used for precision grinding, as they reduce the maximum chip thickness and enable ductile material removal. However, fine-grained grinding wheels with soft bonds are prone to strong wear, which reduces the overall efficiency and productivity of the grinding process. Coarse-grained grinding wheels can be a possible solution to this issue. Due to their large grain size and mostly hard bonds, they are less prone to wear. The challenge in the application of coarse-grained grinding wheels, however, is the process layout based on the critical chip thickness, which should not be exceeded to enable ductile grinding. When calculating the maximum chip thickness, a stochastic distribution of the grains is assumed, which is only given to a limited extent with coarse-grained grinding wheels.
In this research, the calculation of the maximum chip thickness of coarse-grained diamond grinding wheels is discussed and plunge cut grinding experiments are conducted using diamond grinding wheels with grit sizes of D301 and D851. The evaluation of the material removal mechanism is carried out with help of surface texture and surface roughness, which are measured by white light interferometry. Based on the results, it can be shown that the common formula for calculating the maximum chip thickness for coarse-grained diamond grinding wheels can only be used to a limited extent. The measurements of surface roughness and surface texture show that ductile grinding with coarse-grained diamond grinding wheels is possible.

Precision grinding, coarse-grained diamond grinding wheels, surface roughness

1. Introduction

In grinding of brittle-hard materials, the material removal mechanisms play a central role in the formation of the surface of the workpiece. The material-dependent critical chip thickness $h_{cu,crit}$ in this context according to Bifano describes the maximum tolerable chip thickness which causes a ductile material removal mechanism [1].

In design of grinding processes, the decisive parameter for calculating the transition from ductile to brittle material removal is the maximum chip thickness $h_{cu,max}$, which should be below the critical chip thickness $h_{cu,crit}$ in order to be able to machine ductile [2]. The calculation of $h_{cu,max}$ requires the determination of the active cutting edge number C_{kin} and the grain shape factor r, as shown in (1) according to [2].

$$h_{cu,max} = \left(\frac{4 \cdot v_w}{v_c \cdot C_{kin} \cdot r} \sqrt{\frac{a_e}{d_s}}\right)^{1/2} \qquad (1)$$

This relationship, established by Malkin, applies specifically to rectangular cutting cross sections. Accordingly, the number of active cutting edges per area has effect on the maximum chip thickness $h_{cu,max}$ and thus the dominant material removal mechanism [2]. Therefore, fine-grained grinding wheels are generally used for precision grinding. However, fine-grained grinding wheels with soft bonds tend to wear heavily, which reduces the overall efficiency and productivity of the grinding process. Coarse-grained grinding wheels are a potential solution to this problem. Due to their large grain size and usually hard bonds, they are less prone to wear [3, 4]. However, the challenge in their use is the process design based on the critical chip thickness. In calculating the maximum chip thickness, a stochastic distribution of the grains is assumed, which is only given to a limited extent with coarse-grained grinding wheels.

The issue of whether Malkin's equation can be applied to coarse-grained grinding wheels and whether precision grinding with coarse-grained grinding wheels is possible is addressed in this paper.

2. Experimental setup and analysing methods

In this research, plunge cut grinding experiments are performed on BK7 glass and grooves are generated. The kinematics of the grinding experiments are shown in figure 1. Single grooves are generated, in order to investigate larger areas, additional experiments with a crossfeed f_a are performed, cf. figure 1. Furthermore, the depth of cut a_e is varied with 2 µm, 3 µm and 4 µm. The cutting speed v_c is kept constant for all experiments to 30 m/s. The feed rate v_w is also kept constant at 10 mm/min. An overview of the applied experimental settings is given in Table 1. The process parameters were chosen so that the critical chip thickness $h_{cu,crit}$ = 47 nm of BK7 glass is not exceeded. The maximum chip thickness in these experiments is $h_{cu,max} \leq 8$ nm and was determined as described by Brinksmeier et al. [4].

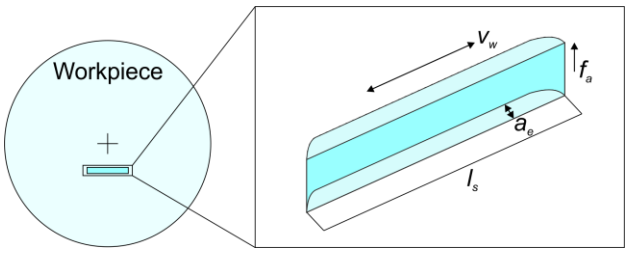

Figure 1. Kinematics of the plunge cut grinding experiments.

Table 1 Experimental settings.

Machine: Cranfield Precision TTG 350 Twin Turret Generator		
Material: N-BK7 Glass		
Process: Plunge cut grinding		
Parameters:		
v_c = 30 m/s	v_w = 10 mm/min	f_a = 50 µm (D301)
n = 7640 U/min	a_e = 2 ; 3 ; 4 µm	f_a = 100 µm (D851)
Grinding fluid: Emulsion		
Tools: Coarse-grained diamond grinding wheel, D301and D851 (reverse plated)		

Grinding experiments were performed on a Cranfield Precision TTG 350 Twin Turret Generator. The experimental setup is shown in Figure 2. A workpiece with a diameter of 50 mm and a thickness of 10 mm is clamped in the main spindle. The tool is located on the vertical grinding spindle.

Figure 2. Experimental setup.

The generated surface topography is measured using white light interferometry (WLI). An objective with 50x magnification and a measuring area of 0.34 mm x 0.34 mm is applied for topography characterization.

3. Results

An exemplary result of a single groove is shown in figure 3. The surface shown was generated with a grinding wheel of grit size D851 and a depth of cut of a_e = 4 µm. It can be seen that the surface shows chipping and cracking, which results in an arithmetic mean height Sa = 211 nm, indicating a brittle material removal mechanism. This result is not expected, since a ductile separation meachanism should prevail and the critical chip thickness is not exceeded. Therefore, it can be concluded that the calculated maximum chip thickness is subject to limitations with regard to the removal mechanism. This may be due to the fact that coarse-grained grinding wheels are used, for which a stochastical distribution of grains only applies with restrictions, and the equation for the maximum chip thickness is based on finer-grained grinding tools.

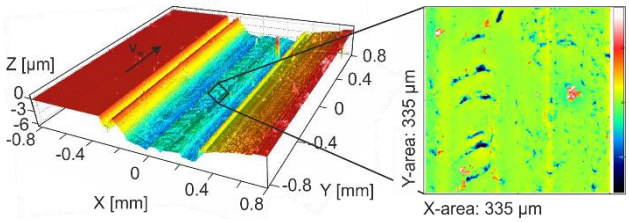

Figure 3. Generated surface texture for a D851 grinding wheel and depth of cut a_e of 4 µm.

The summarized results of the grinding experiments with a crossfeed are shown in figure 4. Here, the arithmetic mean height Sa is considered. The results show the mean value of three individual measurements. The error bars represent the minimum and maximum measured values. A cut off of λ_c = 80 µm was used for the evaluation.

The results show that low roughness Sa between 10 nm and 25 nm can be achieved. However, a relatively high deviation of partly ± 5 nm of the measurement results occurs. As the surface roughnesses show, the generated grooves have only isolated chipping and the dominant material removal mechanism is ductile.

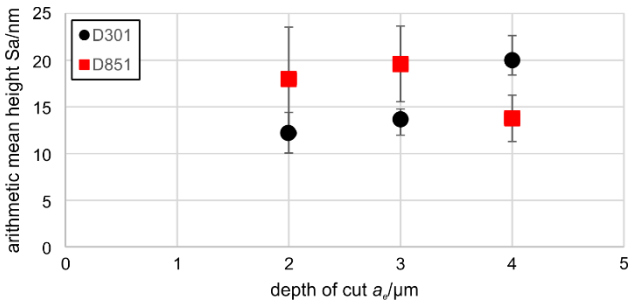

Figure 4. Generated surface topography (arithmetic mean height Sa, measuring area: 0.34 mm x 0.34 mm, λ_c = 80 µm) of the plunge cut grinding experiments with D301 and D851 grinding wheels, crossfeed and varied depth of cut a_e.

4. Summary

Based on the results, it can be shown that the equation for the maximum chip thickness in plunge cut grinding of individual grooves is of limited use in the case of the application of coarse-grained grinding wheels. However, if a crossfeed is used, a ductile material removal mechanism is dominant, resulting in surface roughness close to the optical range. The results deviating compared to the experiments without crossfeed presumably refer to the change in process control. Furthermore, the results show that precision grinding with coarse-grained diamond grinding wheels is possible in principle and that almost optical surface finish can be achieved.

Acknowledgements

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