Investigation of a novel tool concept for ductile grinding of optical glass

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Introduction

In this work a novel tool concept for ductile grinding of optical glass is presented. In contrast to coventional precision grinding technologies, electroplated coarse grained diamond wheels with grain sizes of approx. 100 µm are used in order to obtain longer tool life and thus achieving ductile grinding of large aspheric shapes. The essential requirement for a successful application of coarse grained diamond wheels in ductile grinding of optical glass is the generation of a special grinding wheel topography consisting of flattened grains with a very constant peripheral envelope, resulting in a minimized radial runout of the grinding wheel (cf. fig. 1) [Kan95].

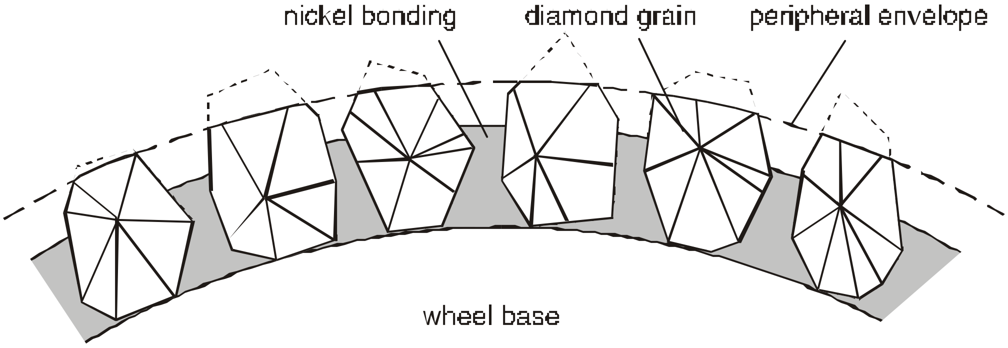

Fig. 1: Intended grinding wheel topography after dressing.

In a first step, a special dressing technology for coarse grained diamond wheels was developed. The dressing time was found to be strongly dependent on the dressing wheel speed. The suitability of the novel tool concept for ductile grinding was tested in surface grinding of SF6 glass. Ductile mode was achieved with similar cutting parameters as known from precision grinding with fine grained wheels [Bif88].

Experimental

The experimental setup for the dressing and grinding experiments is shown in fig. 2. In dressing configuration the grinding wheel performs the infeed motion in x-direction, while the dressing wheel oscillates in z-direction. For the surface grinding experiments x is the feed direction, while the infeed motion is carried out by the workpiece in y-direction. The glass workpiece is mounted on a vacuum chuck below the grinding wheel. The radial error motions of the air bearing dressing and grinding spindles are less than 25 nm. Precision stages with a resolution of 0.1 µm were used for motion in x-, y-, z-directions. The resolution in y-direction is improved to 10 nm due to a 5° tilt of the stage. Grinding forces are recorded with a Kistler 9256 piezo electric transducer with a threshold < 0,002 N. Both dressing and grinding operations are performed by supplying a coolant emulsion.

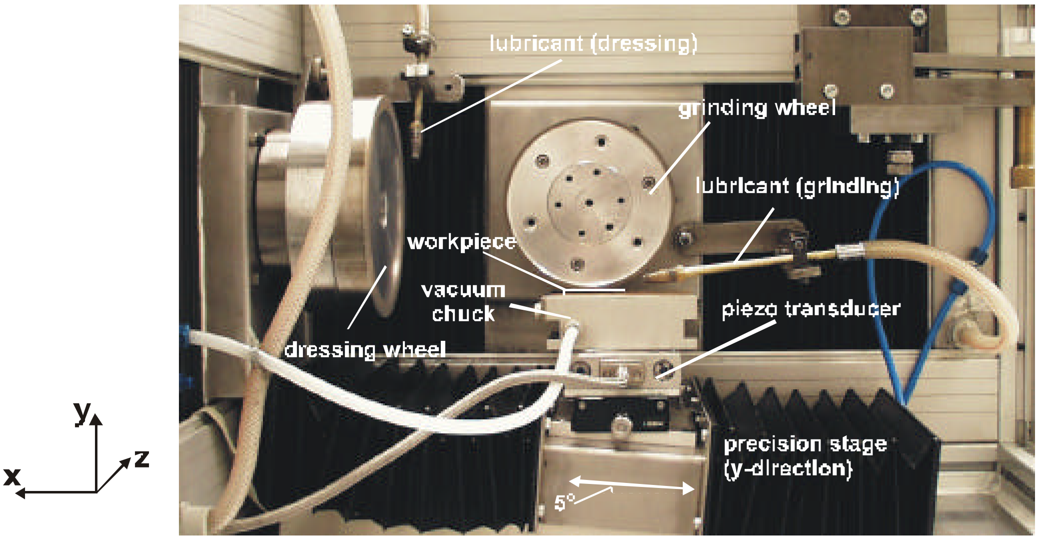

Fig. 2: Experimental setup for dressing and surface grinding with coarse grained diamond wheels.

Dressing of coarse grained diamond wheels

For dressing the diamond grinding wheels only the diamond tops were machined, since the electroplated wheels exhibit a single abrasive layer. Cutting the grain tops results in flattened diamonds on a constant peripheral envelope, so that the number of diamond grains active in the grinding process is increased significantly. Moreover, the hard bonding material leads to a reduced probability of grain tear-out, compared to resin or metal bonded grinding wheels.

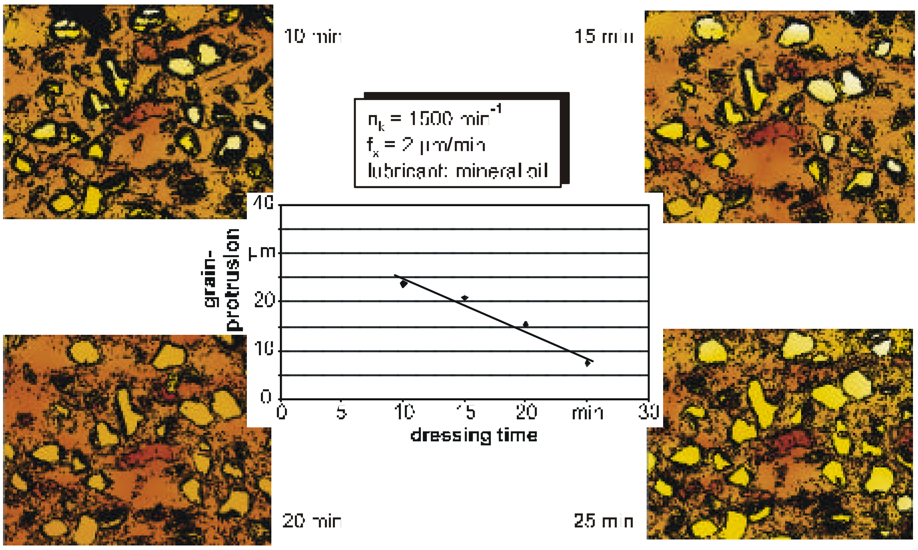

Fig. 3: Grain protrusion vs. dressing time.

For studying the material removal mechanisms and -rates, experiments were performed for different dressing wheel speeds (600 rpm - 1500 rpm). Feed rate was $f_x = 2$ µm/min. The dressing wheel was a D15 metal bonded diamond cup wheel. The removal rate was characterized by investigating the grain protrusion on replicas of the wheel topography with a white-light interferometer. The change of wheel topography with increasing dressing time is shown in fig. 3. The slope of the measured average grain protrusion plotted vs. dressing time reflects the material removal rate. The maximum material removal rate was obtained for the lowest dressing wheel speed of $n_k = 600$ rpm.

Dressing of the diamond wheels was performed with a grinding wheel speed $v_c = 30$ m/s which is also the cutting speed in the subsequent grinding experiments. With a feed rate $f_x = 2$ µm/min and a dressing wheel speed $n_k = 600$ rpm radial grinding wheel runout of less than 2 µm was obtained. The radial runout was investigated using a Mahr inductive dial comparator with a resolution of 0.2 µm.

Grinding experiments

The material removal mechanism for precision grinding of SF6 glass with electroplated coarse grained diamond wheels was studied in several grinding experiments. In fig. 4 roughness R_a is shown for different feed rates and depths of cut. The roughness R_a is strongly influenced by the feed rate v_f, while the depth of cut has a considerably lower effect on surface topography. For $v_f = 1$ mm/min ductile material removal is obtained for all investigated depths of cut. Increasing the feed rate from 1 mm/min to 5 mm/min leads to semi-ductile material response. Further increase of the feed rate from 5 mm/min to 10 mm/min results in brittle material removal. Only for a depth of cut $a_e = 1$ µm semi-ductile surface topography was reached even with $v_f = 10$ mm/min.

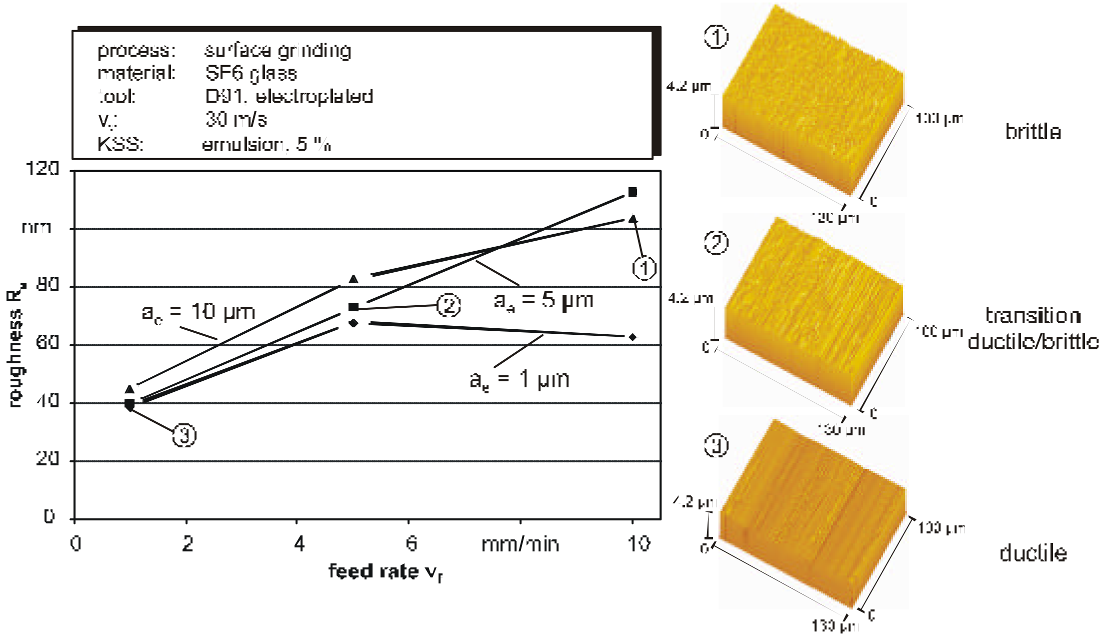

Fig. 4: Roughness R_a and material removal mechanisms vs. feed rate v_f for SF6 glass.

In a number of publications (cf. [Kom97]) the existence of a critical undeformed chip thickness for ductile machining of glass is postulated. The undeformed chip thickness h_{cu} for surface grinding is given by

$$h_{cu} = \frac{a_e \cdot v_f}{v_c} \qquad (1)$$

with depth of cut a_e, feed rate v_f and cutting speed v_c. In our experiments we found different material removal mechanisms even for constant undeformed chip thickness h_{cu} depending on feed rate v_f. This hints at the existence of a critical feed rate as described by Blackley and

Scattergood for diamond turning of brittle materials [Bla91]. Below this feed rate, microfracture induced in the uncut shoulder will not replicate below the cut surface plane (cf. fig. 5). Consequently, constant undeformed chip thickness can result in both, ductile or brittle material removal, depending on the ratio of feed rate to depth of cut.

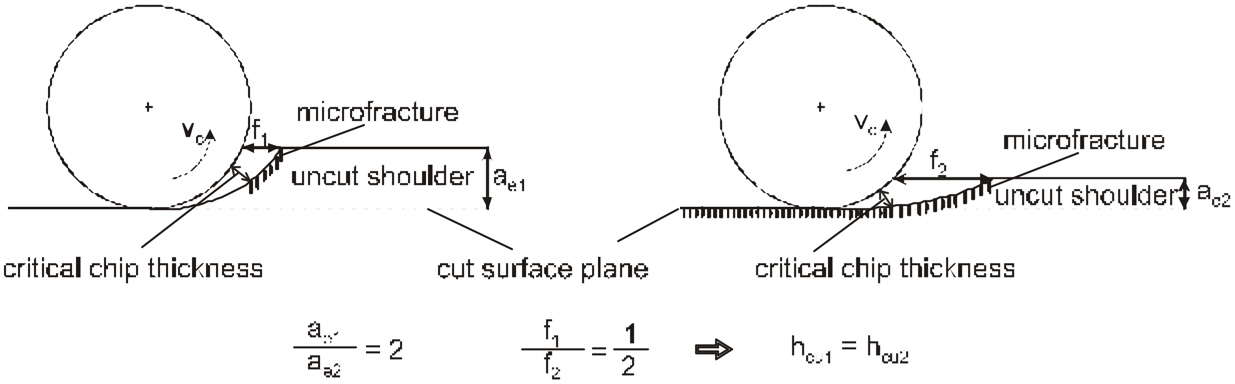

Fig. 5: Effect of feed rate and depth of cut on surface topography.

Conclusion

We have shown that coarse grained diamond wheels with grain sizes of appr. 100 µm can be successfully applied for ductile grinding of glass. The essential requirement for ductile material removal is a very constant peripheral envelope of the diamond tops which has to be in the range of the depth of cut of a few micron. Dressing of the electroplated grinding wheels was performed by grinding the diamond tops with a diamond cup wheel. A radial runout of less than 2 µm was achieved.

Grinding experiments were performed with different feed rates and depths of cut. The achieved roughness R_a was found to be strongly influenced by the feed rate v_f. For v_f = 1 mm/min ductile material removal was achieved even with a depth cut a_e = 10 µm.

Further investigations will focus on the application of our surface grinding process to contour grinding of aspherical shapes. We expect, that the surface quality achieved in surface grinding will improve by a contour grinding process due to the superimposing tracks of the grains.

Acknowlegement

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References

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