euspen's 17th International Conference & Exhibition, Hannover, DE, May 2017
www.euspen.eu

Ultra-precision grinding of polycrystalline transparent ceramics

Thomas Bletek[1], Olaf Dambon[1], Fritz Klocke[1]

[1]*Fraunhofer-Institute for Production Technology IPT, Steinbachstr. 17, 52074 Aachen, Germany*

thomas.bletek@ipt.fraunhofer.de

Abstract

Polycrystalline transparent ceramics are an interesting material when optical applications demand high thermal, chemical and mechanical resistance. Due to the material characteristics, the grinding and polishing of these brittle hard materials is challenging. Ultra-precision grinding is a technology to manufacture surfaces with high quality and to reduce the necessary efforts for polishing. Therefore, in this paper results on the influence of the dressing, grinding and tool parameters on the resulting surface roughness and surface integrity when grinding polycrystalline transparent ceramics are shown. The influence of different dressing conditions, different diamond grain sizes, different depth of cut and different feed rates were investigated. The ground surfaces were analysed by white light interferometer, SEM and AFM. Depending on the parameters, roughness values in the range of Sa = 5 nm can be achieved.

Ultra-precision grinding, ceramics, transparent materials

1. Introduction

In optical applications, depending on the demands and the area of operations, different types of transparent materials are used. For lenses in cameras typically amorphous materials such as glass are utilized. When mechanical properties of glass are not sufficient, polycrystalline transparent ceramic materials as aluminium oxide (Al_2O_3) spinel ($MgOAl_2O_3$) or zirconia oxide (ZrO_2) are interesting alternatives [1]. Further advantages of these ceramics are high transmission in a wide range of wavelengths and a high index of refraction [2].

Due to their mechanical properties, ceramics are brittle-hard materials. The machining is challenging and cutting processes with geometrically undefined cutting edges, such as grinding and polishing are applied [3]. For grinding of polycrystalline non-transparent ceramics a lot of research has been conducted in the past [4,5,6]. When high form accuracy and high surface quality are requested on these materials, ultra-precision grinding is a promising technology [7]. Only limited investigations on the influence of the process and tool parameters is available, without quantified data for the parameters, when machining spinel with geometrically undefined cutting edges [8]. Therefore in this study, ultra-precision grinding experiments on spinel with different dressing and grinding conditions are carried out.

2. Ultra-precision grinding

Grinding experiments were conducted using an ultra-precision grinding machine (Moore Nanotech 350 FG). The work piece is mounted on a vacuum chuck. The resin-bonded grinding tools are mounted in an air bearing grinding spindle. The experimental set-up is shown schematically in figure 1.

2.1. Dressing and grinding conditions

The grinding experiments were done with a variation of dressing parameters (feed rate v_{fd}, depth of cut a_{ed}), grinding parameters (feed rate v_f, depth of cut a_e) and diamond grain size. The relevant parameters are listed in table 1. For dressing, in all investigations a rotating metal-bonded diamond tool is used.

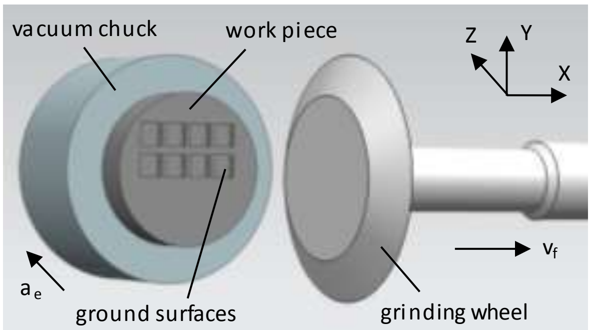

Figure 1. Experimental set-up for grinding

Table 1. Dressing and grinding conditions

Dressing depth of cut a_{ed}	1 µm; 5 µm
Dressing feed rate v_{fd}	1 mm/min; 2 mm/min
Dressing tool	Rotating metal-bonded diamond tool, #800
Grinding depth of cut a_e	1 µm; 2 µm
Grinding feed rate v_f	100 mm/min; 200 mm/min
Grinding contact width a_p	20 µm
Grinding spindle rotation n_g	19 000 min^{-1}
Diamond grain size	#1500; #3000
Grinding wheel diameter d	30 mm
Grinding wheel bond	Resin-bonded

Coolant	Isoparaffin
Workpiece material	Spinel ($MgOAl_2O_3$)
Workpiece material average grain size	0,33 µm

2.2. Measurement

The surface roughness was measured with a white light interferometer (Bruker Contour GT). The arithmetic mean surface roughness Sa is used as a parameter for the analysis because this parameter is typically used for estimating optical surfaces. A scanning electron microscope (Zeiss Neon 40EsB) and an atomic force microscope (AFM) were used additionaly to evaluate the ground surfaces on a qualitative and quantitative base.

3. Results and discussion

The goal of the investigations is to find out how the different parameters influence surface roughness and surface quality.

3.1. Surface roughness

The results concerning surface roughness Sa are shown in figure 2. The dressing parameters and the diamond grain size have the biggest influence on the resulting surface roughness. The effect of the grinding parameters in the considered parameter window is rather small. With a dressing feedrate of v_{fd} = 1 mm, a dressing depth of cut a_{ed} = 1 µm, a diamond grain size of #3000, a depth of cut of a_e = 1 µm and a feedrate of v_f = 100 mm/min a surface roughness of Sa = 5,2 nm can be achieved. Depending on the dressing conditions, the topography of the grinding wheel and the diamond grains are influenced and single exposing grains can be avoided.

The measurements of root mean square roughness Sq confirmed the observations made by the Sa values. Further analysis of the Skewness and Kurtosis Sku and Ssk were not helpful in assessing the visually and optically detectable surface condition in terms of peak or valley defects such as scratches or grooves.

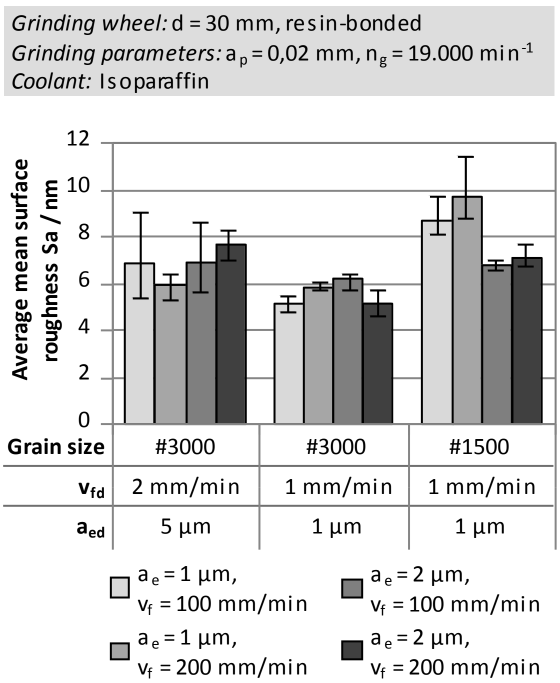

Figure 2. Surface roughness Sa of ground spinel

3.2. Qualitative and quantitative analysis of surface quality

For optical applications also the visual inspection of the surface quality is relevant. SEM measurements of the ground surface with different dressing conditions are shown in figure 3. A much smoother ground surface with fewer grooves and errors is visible when using finer dressing parameters due to reduced exposed grains.

For quantitative analysis concerning the depth of errors, AFM measurements are used. The influence of the different grain sizes is shown in figure 4. Reducing the grain size from #1500 to #3000, a smoother surface with less grooves can be achieved.

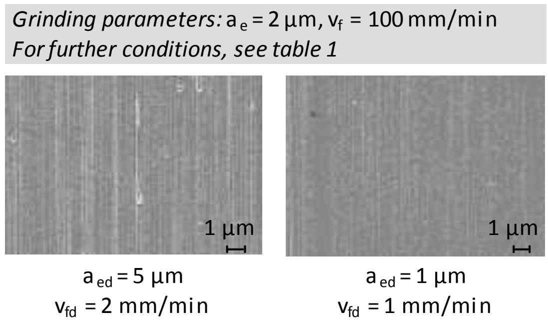

Figure 3. SEM measurements of ground surface depending on dressing conditions

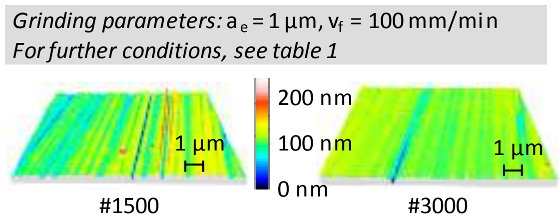

Figure 4. AFM measurements of ground surface depending on diamond grain size

4. Conclusion

Ultra-precision grinding investigations on spinel were carried out using different dressing conditions, different grinding conditions and different grain sizes. The surface roughness and surface quality can be improved and the effort for polishing can be reduced, when using a finer grained grinding tool and when using lower feedrate and depth of cut during dressing. A surface roughness of Sa = 5,2 nm was achieved with a dressing feedrate of v_{fd} = 1 mm, a dressing depth of cut a_{ed} = 1 µm, a diamond grain size of #3000, a depth of cut of a_e = 1 µm and a feedrate of v_f = 100 mm/min.

Additional research will focus on a broader window for the grinding parameters to increase productivity and on further analysis of the influence on the optical properties.

References

[1] Krell A, Hutzler T and Klimke J 2007 *Cer. For. Int.* **84** 50-56
[2] Krell A, Hutzler T and Klimke J 2009 *J. Eur. Cer. Soc.* **29** 207-221
[3] Klocke F 2009 *Manufacturing processes 2: Grinding, honing and lapping* (Berlin Heidelberg: Springer-Verlag)
[4] Denkena B, Köhler J and van der Meer M 2013 *CIRP J. Man. Sci. Techn.* **6** 22-33
[5] Malkin S and Hwang TW 1996 *CIRP Ann.* **45** 569-580
[6] Suzuki H, Kodera S, Nakasuji T, Ohta T and Syoji K 1998 *Int. J. Japan Soc. Prec. Eng.* **32** 25-30
[7] Brinksmeier E, Mutlugünes Y, Klocke F, Aurich JC, Shore P and Ohmori H 2010 *CIRP Ann.* **59** 652-671
[8] Bashe J, Hibbard D, 2009 *SPIE Proc.* **7302** 7302OC