Small hole formation process for zirconia-based ceramics for mould

T. Owaki[1], Y. Ihara[1]
[1]*Osaka Institute of Technology, Japan*
ihara@med.oit.ac.jp

Keywords: Fine ceramics, Grinding, Helical process, Processing conditions, Electrodeposited diamond wheel, Drill for hard brittle material

Abstract

In this study, the ability to form small holes in a newly developed zirconia-based material for mold was investigated. Although the material is an improvement over conventional zirconia ceramics, its precise physical properties are uncertain because the processing method and conditions used to produce it are unknown. In order to use this material as a plastic mold, holes with diameters of about 1 mm and depths of about 3 mm need to be formed, in order to insert the positioning pins. However, it is difficult to produce such small holes in fine ceramics using conventional cutting processes. Therefore, a helical hole formation process was developed based on the use of a grinding tool. This was found to be capable of highly efficient hole formation in both the newly developed mold material and more conventional fine ceramics. For comparison, hole formation was also carried out using a recently developed diamond coated drill.

1. Materials

The material considered in this study has been newly developed for use in plastic molds, and is based on zirconia. It is improved higher wear resistance, smoother part removal property in addition to high toughness, wear resistance and low thermal expansion characteristics that normal zirconia ceramics also has. It is assumed that this material corresponds to partially stabilized zirconia (PSZ), and it will be referred to as such in the remainder of this paper. PSZ is known to maintain its strength and toughness unless it is subjected to a temperature high enough for a phase transition to occur. In the present study, the ability to form small holes in the PSZ, as well as standard zirconia, alumina and silicon nitride was compared. Since the sizes of the work pieces were different in each case, through-hole formation was performed only for alumina and PSZ, whereas blind drilling was performed for standard zirconia and silicon nitride. The holes all had diameters of 1 mm and depths of 2.6 mm. Table 1 shows the properties of the different materials used in this study.

2. Hole formation methods

In the present study, two different hole formation methods were compared. In the helical method, a hole is produced using a cylindrical grinding tool with a diameter smaller that that of the hole being produced. Figure 1 shows a schematic of the helical processing method. The tool is rotated and simultaneously moved in a helical path within the forming hole, this reducing the axial grinding force. However, since the grinding tool can easily bend during processing, it is difficult to obtain a high profile accuracy. Therefore, hole formation was also performed using a newly developed special drill for hard brittle materials, and the results were compared. Table 2 shows the processing conditions for both methods.

Table 1: Material properties

Material		PSZ	Zirconia
Composition		ZrO_2	
Density	g/cm^3	unknown	6.07
Toughness	$MPa\cdot m^{1/2}$	unknown	5
Bending strength	MPa	unknown	1100
Hardness (HV)	MPa	unknown	1300

Material		Alumina	Silicon nitride
Composition		Al_2O_3	Si_3N_4
Density	g/cm3	3.8	3.21
Toughness	MPa√m	3 ~ 4	7
Bending strength	MPa	310	900
Hardness (HV)	MPa	1600	1400

Table 2: Processing conditions

		Helical grinding	Drilling
S	Rpm	66000	10000
F	mm/min	100	1
D	Mm	2.6	
d_1	Mm	0.8	1
d_2	Mm	1	
d_r	Mm	0.1	
d_d	µm/rev	0.003, 0.004, 0.005	
Grains		Synthetic diamond	
Mesh number		#240	
Coating			Diamond

3. Experimental results

3.1 Helical grinding

During hole formation by helical grinding, the measured grinding force was larger for zirconia than for PSZ. Figure 2 shows the change in the hole diameter with hole number for different materials at a depth of cut of 3 µm/rev. The hole diameter (D_S) at the entrance surface is shown in Fig. 2(a), and that (D_F) at the exit surface is shown in Fig. 2(b) for the cases where through-holes were formed. The smaller values at the exit surface are thought to be due to tapering as a result of bending of the tool as its contact area with the side walls becomes larger with increasing depth.

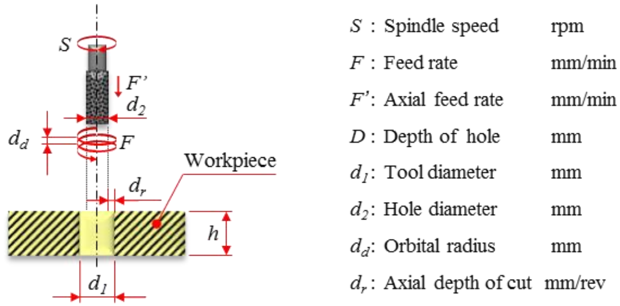
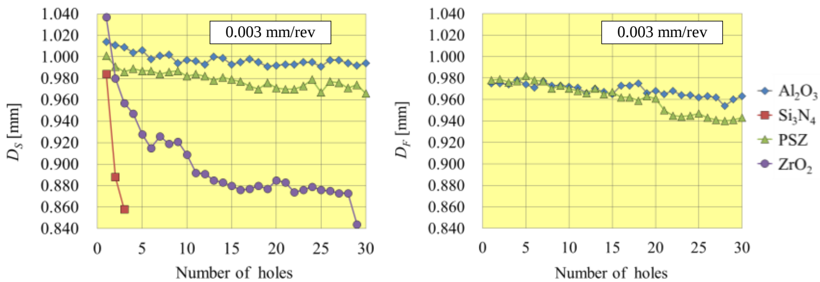


Figure 1: Schematic of helical grinding process

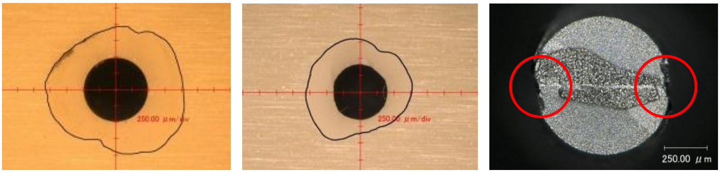


(a) entrance diameter D_S (b) exit diameter D_F

Figure 2: Hole diameters following helical grinding of different materials

3.2 Drilling

Through-hole drilling was carried out for PSZ and alumina. Figures 3(a) and 3(b) show the first and second holes drilled in the PSZ. The axial cutting force increased due to wear of the drill edge during formation of the first hole, and the hole surface after penetration became broken. The effect became more severe during cutting of the second hole, so that the tool edge was damaged, as seen in Fig. 3(c). The red circles indicate regions where the cutting edge has been lost. Since the diameter of the drill edge region decreased as drilling proceeded, the exit hole diameter D_F became smaller. In the case of alumina, although continuous drilling was possible, the processing time was considerably longer than that for helical grinding.



(a) First hole (b) Second hole (c) Tool damage after second hole formation

Figure 3: Holes produced by drilling of PSZ

4. Conclusions

- Using helical grinding, about 3 minutes were required to produce a single hole in PSZ. About 30 holes could be produced with a single grinding tool.
- Since the shape accuracy for helical grinding is poor, a drilling process was also tried. However, it took about 10 minutes to form a single hole, and the tool life was shorter than that for helical processing.

References:

[1] Nakagawa, H., Ogawa, K., Saga, K., 2007, Development of electroplated diamond wheel for helical boring of fine ceramics - 1st report: Wheel end profile and state of abrasive cutting edge interference, Journal of the Japan Society for Abrasive Technology, Vol. 51, No. 11, pp. 662-667 (in Japanese).

[2] Yamaguchi, K., Ihara, Y., 2011, Study on Small Hole Open Process on Ceramics, International Conference on Leading Edge Manufacturing in 21st Century (LEM21), No. 3301.

[3] Mizobuchi, A., Ogawa, H., 2010, Method for optical assessment of finished surfaces obtained by vibration-assisted finishing, Journal of the Japan Society for Abrasive Technology, Vol. 54, No. 3, pp. 145-150 (in Japanese).