Experimental Study on Grinding Surface Roughness of Full-Ceramic Bearing Ring

Songhua Li, Kechong Wang, and Jian Sun

Abstract To solve the problems of low efficiency, high cost, and high difficulty of full-ceramic bearing ring grinding machining, the effect of process parameters such as grinding wheel grain size, grinding wheel speed, workpiece speed, grinding wheel feed rate, and *Z*-axis oscillation rate on the value of ceramic ring surface roughness Ra was studied by MK2710 NC grinding machine. The results show that grinding parameters have different influences on the value of Ra. The value of ceramic ring surface roughness Ra decreases with the grain size becoming smaller. As the grinding wheel speed and workpiece speed increases, the value of Ra decreases. The value of ceramic ring surface roughness Ra increases with the increase of grinding wheel feed rate and *Z*-axis oscillation rate. The determination of the best grinding process will provide the basis for full-ceramic bearing ring precision machining.

Keywords Bearing ring · Grinding parameters · Surface roughness · Single-factor test · Engineering ceramics

1 Introduction

Engineering ceramics with lightweight, high strength, wear resistance, corrosion resistance, high-temperature resistance, small coefficient of thermal expansion, and other excellent properties [1–3] have been widely used in bearing manufacturing industry, aerospace, cutting tool, instrumentation, ceramic armor, biological medicine, and other fields, and the material properties of bearing steels and engineering ceramics are shown in Table 1. There is no doubt that engineering ceramics have many advantages compared with bearing steel. However, it is hard and brittle, which also cause a lot of trouble in processing and manufacturing [4]. Therefore, it is of great significance to study the machinability of engineering ceramics to obtain high-quality ceramic parts.

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Table 1 Performance comparison between bearing steel and engineering ceramics

Indicators	Unit	Steel	SiC	ZrO_2	Si_3N_4
Density	g/cm^3	7.85	3.10–3.20	5.7–6.05	3.20–3.30
Coefficient of thermal expansion	10^{-6}/K	10.0	4.0–4.8	7.0–10.5	3.1–3.3
Modulus of elasticity	GPa	208	410–450	180–210	300–320
Poisson's ratio	–	0.30	0.14	0.30	0.26
Hardness	HV	700	2100–2400	800–1500	1300–1800
Bending strength	MPa	2400	350–450	900–1200	800–1000
Compressive strength	MPa	–	2250–3500	1000–3000	2000–3500
Bending toughness	$MPa{\cdot}m^{1/2}$	25	3.5–4.5	8.0–10.0	5.0–7.0
Thermal conductivity	W/m·K	30–40	150	2–3	29–35

Up to now, the main reason for restricting the wide application of ceramic materials is the high processing cost, in which the grinding processing cost accounts for more than 80% [5]. Scholars worldwide have done a lot of research on engineering ceramics, but there is little research on the grinding surface roughness of ceramic bearing rings. Wu et al. [6] proposed a new surface roughness model for brittle materials based on a series of experiments on grinding of SiC ceramics, and their results indicate that the predicted values of the model have the advantage of high goodness of fit with the experimental results and satisfactory effect. Ma et al. [7] studied the removal mechanism of hard–brittle material and developed a cutting force model of hard–brittle material based on fracture mechanics. The results will reflect the fracture removal process of brittle material. Wan et al. [8] created a finite element model of silicon nitride grinding based on virtual abrasives, simulated the subsurface damage depth, and analyzed the influence of the grinding parameters, such as the wheel speed, workpiece speed, and grinding depth on the subsurface damage depth. It is obvious that the research on high-efficiency and low-cost processing methods needs further research in actual production.

For this purpose, this paper takes the outer ring of zirconia ceramic bearing as the research object, and MK2710 NC grinding machine is selected for the experiment to discuss the effect of processing parameters on the value of zirconia ceramic ring surface roughness Ra.

In this paper, Sect. 2 describes the environment and equipment used for the experiments, Sect. 3 provides an analysis and discussion of the results of the experiment, and Sect. 4 shows the main conclusions obtained from the experiment. Hence, this paper has a positive effect on the rational selection of process parameters, improving surface quality and reducing production costs during the production and processing of zirconia ceramic ring.

2 Experimental Work

2.1 Experimental Materials and Conditions

In the grinding experiments, our research objects are zirconia ceramic outer rings, which are provided by the Shanghai Institute of Ceramics of the Chinese Academy of Sciences. The size of the zirconia ceramic ring sample is φ75 mm × φ63 mm × 16 mm. Table 2 lists the main mechanical properties of the zirconia ceramics used in the experiment.

In this experiment, resin-bonded diamond grinding wheels are used as shown in Fig. 1, and its specifications are showed in Table 3. All experiments are carried out under wet conditions, which is a 5% solution of water-based cooling of fluid. In addition, the flow rate of grinding fluid is controlled at the level of 100 L/min.

Table 2 Performance of zirconia ceramic rings

Density (g cm^{-3})	Elasticity modulus (GPa)	Thermal expansivity (10^{-6} K^{-1})	Poisson's ratio	Fracture toughness (MPa $m^{1/2}$)	Hardness (HRC)	Bending strength (MPa)
5.88	195	8.75	0.30	10.50	78	750

Fig. 1 Diamond grinding wheel

Table 3 Performance indicators of the diamond grinding wheel

Indicators	Value
Outer diameter (mm)	50
Thickness (mm)	5
Concentration (%)	100
Bond	Resin

Table 4 Parameters of the single-factor experiment

No.	Grain size (#)	Grinding wheel speed (m/s)	Workpiece speed (r/min)	Grinding wheel feed rate (μm/min)	Z-axis oscillation rate (mm/min)
1	40, 60/70, 80/100, 120/140, 140/170, 230/270, W20	35	100	20	600
2	80/100	20, 25, 30, 35, 40, 45, 50, 55, 60, 65	100	20	600
3	80/100	35	100, 200, 300, 400, 500, 600, 700, 800	20	600
4	80/100	35	100	4, 6, 8, 10, 12, 14, 16, 18, 20	600
5	80/100	35	100	20	100, 200, 300, 400, 500, 600, 700, 800, 900

2.2 *Experimental Design*

In order to investigate the effect of processing parameters of zirconia ceramic ring on the value of surface roughness Ra, single-factor experiments are used to analyze the influence of grinding wheel grain size, grinding wheel speed, workpiece speed, grinding wheel feed rate, and *Z*-axis oscillation rate on the value of zirconia ceramic ring surface roughness Ra. The parameters of the single-factor experiment are shown in Table 4.

2.3 *Experimental Apparatus and Measuring Instruments*

Due to the good performances of the high-precision MK2710 NC grinder, it is selected as our experimental platform. Its minimum resolution does not exceed 0.001 mm and the maximum grinding spindle speed can be up to 36,000 r/min. Our experimental platform is shown in Fig. 2. As shown in Fig. 3, we can measure the value of zirconia ceramic ring surface roughness Ra by the Surtronic 25 Taylor Hobson roughness measuring instrument, and the measurement error does not exceed 0.001 μm. At the same time, we can use the Hitachi S-4800 Cold Field Emission Scanning Electron Microscope to observe the surface topography of the zirconia ceramic rings, which allows us to see more clearly.

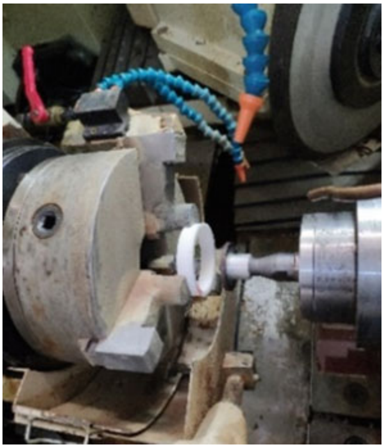


Fig. 2 Grinding experiment system

Fig. 3 Taylor Hobson roughness measuring instrument

In addition, a number of measures have been taken with data processing in order to make our test results more accurate. Six sets of data are measured along the circumference direction for each ceramic ring, and after deleting the maximum and minimum values, the average of remaining four sets of data is the final experimental result.

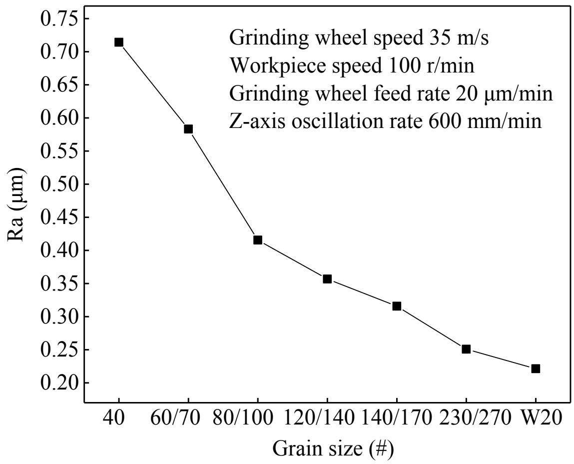


Fig. 4 Effect of the grinding wheel grain size on the value of Ra

3 Analysis of Experimental Results and Discussions

3.1 Effect of the Grinding Wheel Grain Size on the Value of Ra

As can be seen in Fig. 4, the value of Ra decreases with the decrease of grinding wheel grain size. At the initial stage, the roughness changes dramatically, but as the decrease of grain size, the roughness changes tend to be flat, the surface roughness gets decreased, and the surface quality becomes better. The reason for this phenomenon is that the larger the grain size, the wider the scratches produced by the grain on the surface, the greater the height of the grooves and bulges, and the worse the surface quality. Furthermore, it can be clearly seen from Fig. 5 that there are many visible grinding grooves on the grinding surface of the ceramic bearing ring. And grinding wheel grain size is smaller, and grinding grooves are showing a narrow, smooth state.

3.2 Effect of the Grinding Wheel Speed on the Value of Ra

The effect of grinding wheel speed on the value of Ra of ceramic bearing ring is shown in Fig. 6. As can be seen in Fig. 6, the value of Ra decreases with the increase of the grinding wheel speed. When the grinding wheel speed is up to 55 m/s, the grinding wheel speed has little effect on the value of Ra of ceramic bearing ring and the value basically tends to be stable. As is known to all, the maximum undeformed cutting thickness of single grain decreases with the increase of the grinding wheel speed, the grinding force of single grain gets decreased and specific grinding energy gets

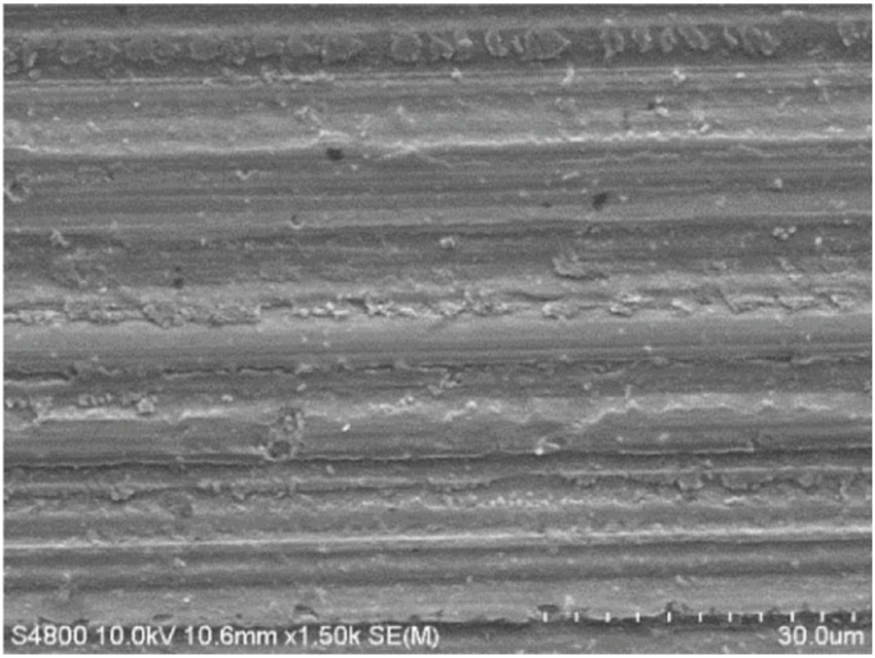
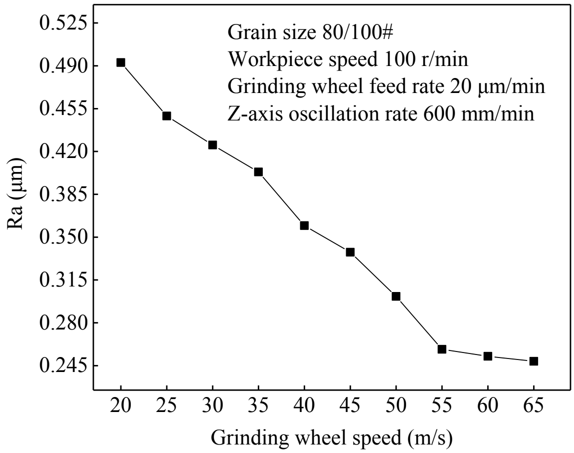


Fig. 5 SEM image

Fig. 6 Effect of the grinding wheel speed on the value of Ra



increased. The proportion of plastic removal of the ceramic material gets increased and the surface quality of the ceramic ring will become better [9, 10]. Therefore, the grinding wheel speed can be increased in the grinding process, which will be more conducive to improving the surface quality of the ceramic ring.

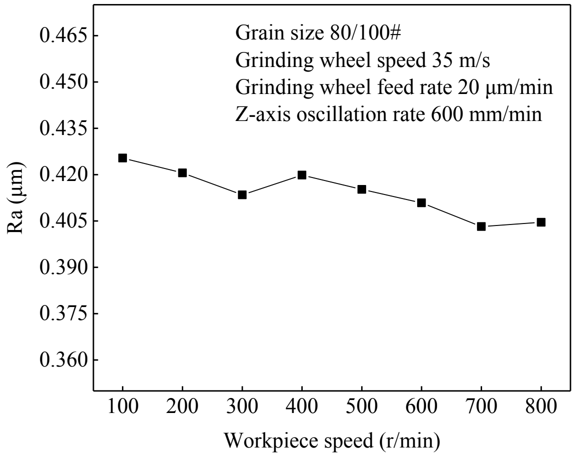


Fig. 7 Effect of the workpiece speed on the value of Ra

3.3 Effect of the Workpiece Speed on the Value of Ra

We can clearly see from Fig. 7 that the effect of the workpiece speed on the value of Ra of ceramic bearing ring is not very obvious. But as the workpiece speed increases, the surface roughness generally shows a slight downward trend. Compared with the high-speed rotating grinding wheel, the workpiece speed has little effect on the test results. However, with the continuous increase of workpiece speed, the scratches produced by the abrasive on the surface of the ceramic ring become denser and denser. Consequently, the roughness of ceramic bearing ring tends to decrease.

3.4 Effect of the Grinding Wheel Feed Rate on the Value of Ra

The result shows that the value of Ra of ceramic ring generally increases with the increase of the grinding wheel feed rate, and the variation of the value of Ra with the grinding wheel feed rate is as shown in Fig. 8. When the grinding wheel feed rate does not exceed 10 μm/min, the surface roughness is small and stable. With the further increase of grinding wheel feed rate, the cutting thickness of single grain is up to the critical cutting depth of plastic and brittle removal, thus the proportion of brittle removal of the ceramic material gets increased [11]. As a result, surface roughness increases sharply and it results in rapid deterioration of surface quality.

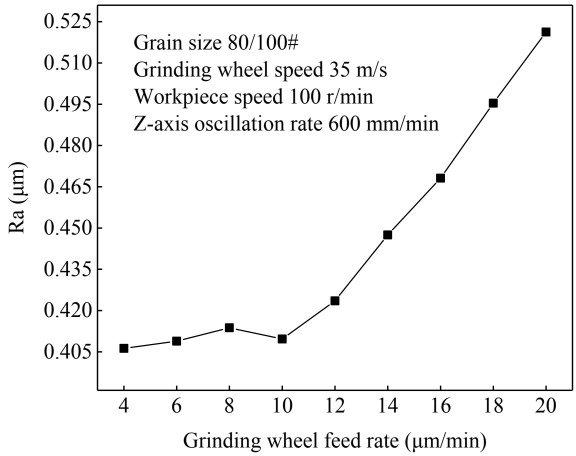


Fig. 8 Effect of the grinding wheel feed rate on the value of Ra

3.5 Effect of Z-axis Oscillation Rate on the Value of Ra

The variation of the value of Ra of zirconia ceramic ring is as shown in Fig. 9. We can clearly see from Fig. 9 that the trend of Ra varies with the variation of *Z*-axis oscillation rate. With the increase of *Z*-axis oscillation rate, the surface roughness increases continuously. The reasons for this trend are as follows: when the *Z*-axis oscillation rate is low, the scratches produced by abrasive on the surface of the ceramic ring are dense and the value of Ra is small. With the continuous increase of the *Z*-axis oscillation rate, the scratches on the surface of the workpiece become more and more sparse, and the surface roughness increases significantly.

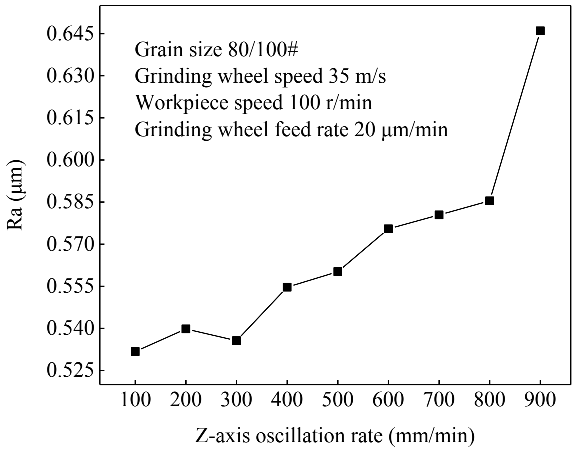


Fig. 9 Effect of *Z*-axis oscillation rate on the value of Ra

4 Conclusions

During the grinding process of the zirconia ceramic bearing ring, the value of Ra varied with processing parameters. The surface quality of zirconia ceramic ring was closely related to the removal mode of surface material. Hence, a reasonable selection of grinding parameters could predict and control the surface roughness of zirconia ceramic ring, which would be of great significance for production and processing.

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