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PROCESS PARAMETERS IN GRINDING OF Si_3N_4 CERAMICS WITH VIRTRIFIED BOND DIAMOND GRINDING WHEEL

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Silicon nitride ceramics are known as "all-round champions" in ceramic materials, but excellent performance has also brought great difficulties to the grinding process. In this paper, we use virtrified bond diamond grinding wheels to grind silicon nitride ceramics. The effects of grinding wheel line speed (v), diamond abrasive grain size, and grinding wheel feed (fr) on the removal rate of grinding and surface roughness of silicon nitride ceramics were researched. The results show that the overall grinding rate of silicon nitride ceramics increases with the wheel line speed. The coarse diamond abrasive particle size and greater feed lead to higher grinding rate, while the finer diamond abrasive result in better processed surface. By optimizing parameters of grinding parameters, the grinding efficiency and accuracy of silicon nitride ceramics are greatly improved. Finally, the grinding rate of silicon nitride ceramics is as high as 0.4528 g/min, and the surface roughness (unpolished) is 0.554μm after grinding.

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Keywords: Grinding, Silicon nitride ceramics, Virtrified bond diamond grinding wheel, Removal rate of grinding, Roughness

1.Introduction

As a typical engineering ceramic material, Si_3N_4 ceramic has the advantages of high strength, high hardness, wear resistance, chemical resistance, etc. [1, 2], and has shown remarkable application value and broad application prospects in high-tech fields [3]. However, the material structure of Si_3N_4 ceramic determines the material brittleness, hardness, and mechanical processing difficulties which limit its application in engineering [4]. For this reason, silicon nitride ceramic production is usually produced using net shape sintering and then machined to the required size by grinding [5]. Grinding of silicon nitride ceramics can be achieved with diamond grinding wheels. At present, the grinding of silicon nitride ceramics is based primarily on resin-based diamond grinding and subsequent polishing. However, this process is inefficient and costly, and it is difficult to satisfy the needs of engineering applications [6, 7]. The ceramic binder which has good rigidity, high temperature resistance and good shape retention during grinding, is appropriate for precision grinding [8]. At the same time, the ceramic binder has a strong grip on the abrasive particles, and the grinding wheel can adjust the hardness and the number of pores in the manufacturing process, which is favorable for improving the grinding performance of the grinding wheel [9, 10]. At present, the research on high-precision processing of silicon nitride ceramic materials utilizing virtrified bonded diamond grinding wheels is not sufficient. Further study of virtrified bonded diamond grinding wheels for silicon nitride processing can promote the development of precision machining technology for ceramic materials and promote the use of virtrified binder diamonds.

In this study, the influence of wheel speed, abrasive grain size, and wheel feed rate on the material removal rate and surface roughness of the ceramic was researched. Moreover, a process

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reference is provided for obtaining a high-quality surface of silicon nitride ceramic by grinding with virtrified bond diamond grinding wheel.

2. Experimental

The experimental Si_3N_4 ceramics are Φ30×45mm cylindrical parts. The performance indicators are shown in Table 1. The surface grinding of the silicon nitride ceramic surface was performed using a M7130 CNC compound grinder. The maximum speed of the M7130 grinding wheel shaft is 3000 r/min, the feed resolution is 0.005 mm, the axial oscillation speed is 50 mm/min, the radial feed speed is 0.04 mm/min. The grinding coolant uses a water-based grinding fluid with a volume ratio of 1:20. The grinding tool is a 1A1 (250*75*25*10mm)surface grinding virtrified bond diamond grinding wheel. There are five types of ceramic binder diamond grinding wheels. The abrasive grain size in No.1 wheel is 140/170, the diamond grain size in No.2 wheel is 170/200, the diamond grain size in No.3 wheel is 200/230, and the diamond grain size in No.4 wheel is 270/300. The diamond abrasive grain size in No.5 wheel is 325/400, and the diamond abrasive concentration in the above grinding wheel is 160%. The grinding work environment parameters are shown in Table 2. The surface roughness of the sample is measured by the white light interferometer (Contour GT-IM). The Scanning Probe Image Processor software was used to simulate three-dimensional images of silicon nitride ceramic surfaces after grinding.

Table 1. Properties of silicon nitride ceramics.

Density	Hardness	Flexural	Fracture strength	Modulus of toughness elasticity
3.2g/cm^3	1800HV	800Mpa	4.5Mpa m$^{1/2}$	320GPa

Table 2. The grinding work environment parameters.

Number	Parameters	Contents				
		1#	2#	3#	4#	5#
A	Abrasiveparticle size ($^{\#}$)	140/170	170/200	200/230	270/300	325/400
B	Grinding wheel linear speed (m/s)	20	25	30	35	40
C	Workpiece speed (mm/s)	30	30	30	30	30
D	Grinding wheel feed (mm)	0.02	0.03	0.06	0.099	0.12

3. Results and discussion

3.1. The effect of diamond grinding wheel line speed on removal rate of grinding

Fig. 1 is the relationship between line speed of diamond grinding wheel and the removal rate of grinding. From Fig. 1, it be observed that as the line speed of the grinding wheel increases, the removal rate of the diamond wheel with different particle sizes increases. This is because the increase in the line speed of the grinding wheel lead to an increase in the number of time that the diamond abrasive scratches the silicon nitride ceramic per unit time, so that the quality of the worn-out silicon nitride ceramic increases. Therefore, under normal working conditions, it is recommended to use high line speed to improve the processing efficiency.

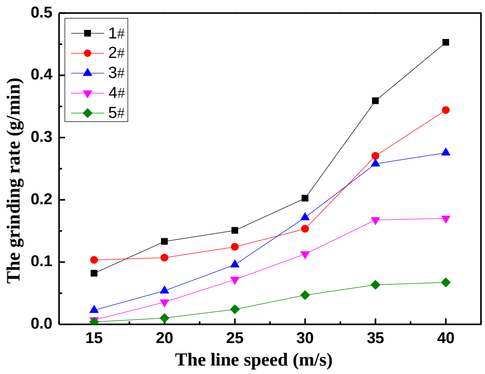

Fig.1. The relationship between diamond wheel line speed and grinding rate.

3.2. The effect of diamond abrasive particle size on removal rate of grinding

When the line speed is 40m/s, Fig. 2 is the relationship between the diamond abrasive grain size and the removal rate of grinding. With the same line speed, the grinding rate of silicon nitride ceramic increases with the increase of diamond abrasive particle size. As the diamond abrasive grain size increases, the height of the diamond abrasive grains on the working surface of the grinding wheel becomes large, and the average height of the abrasive grain grinding blade also increases. Therefore, the wear scar on the surface of silicon nitride becomes thicker and deeper, which eventually leads to an increase in the grinding rate of silicon nitride. In summary, in order to improve the efficiency of grinding process, large-size diamond abrasives can be considered.

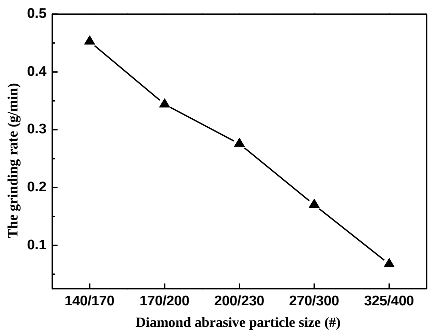

Fig.2. The relationship between the diamond abrasive grain size and the grinding rate.

3.3. The effect of diamond grinding wheel speed on the surface roughness of silicon nitride ceramics

The experiment used 2# grinding wheel,when the grinding wheel feed was 0.05mm, the effects of different diamond wheel line speed on the surface roughness of silicon nitride ceramic were tested respectively. The results are shown in Fig. 3 and Table 3. The experimental results shown that the surface roughness value of the silicon nitride ceramic workpiece decreased as the wheel line speed increases.

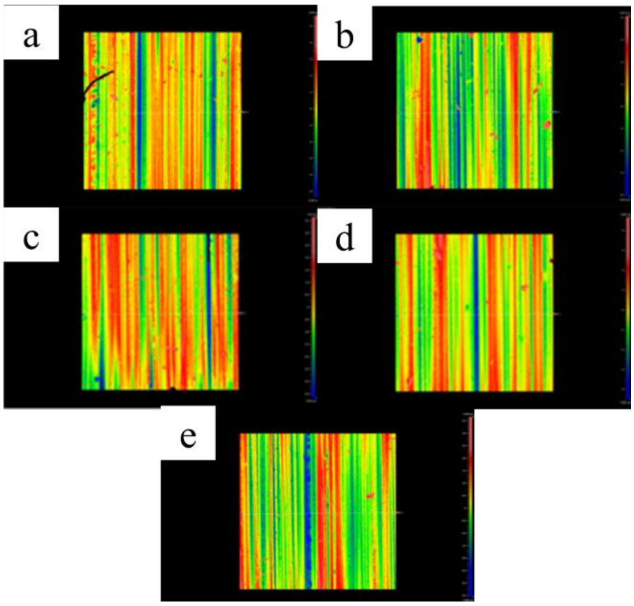

Fig.3.The images of different diamond wheel line speed on the surface roughness of silicon nitride (a: 20m/s, b: 25m/s, c: 30m/s, d: 35m/s, e: 40m/s).

Table 3 Surface roughness value of silicon nitride at different line speeds.

Items	Content				
Speed (m/s)	20	25	30	35	40
Surface roughness (μm)	1.212	1.029	0.851	0.867	0.814

Silicon nitride ceramic materials are difficult to process. At the beginning of grinding, grinding wheels and workpieces are in a state of elastic contact and sliding, micro-cracks are generated on the ground surface, diamond abrasives are rubbed, and silicon nitride ceramics are broken into crumbs. Then the removal begins, at which point the surface roughness reaches its maximum value, and finally it enters the grinding phase without feed. In this process, as the line speed of the grinding wheel increases, the number of abrasive particles participating in workpiece grinding per unit time increases, the maximum grinding thickness of a single abrasive particle becomes thinner, the micro cracks on the surface of the material decrease, and the surface roughness decreases.

According to the results of the influence of the linear velocity on the surface roughness, at the same time, considering the processing efficiency and the quality requirements of the processed workpiece, it is recommended to use the high-speed grinding method as far as possible.

3.4. The effect of diamond abrasive particle sizes on surface roughness of silicon nitride ceramics

When the linear speed of the diamond grinding wheel is 40m/s, and the feeding amount of the grinding wheel is 0.05mm, the silicon nitride ceramics are grinded with different grain sizes of diamond grinding wheels. The surface roughness image and numerical values of the processed silicon nitride ceramics are shown in Fig. 4 and Table 4.

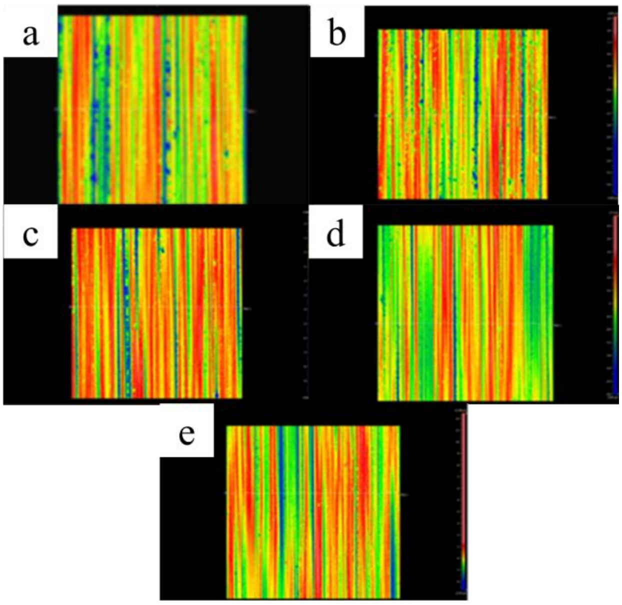

Fig.4. The image of different diamond abrasive particle sizes on the surface roughness of silicon nitride (a: 140/170, b: 170/200, c: 200/230, d: 270/300, e: 325/400).

Table 4 Roughness value of the silicon nitride silicon with different diamond abrasive particle sizes.

Items	Content				
Particle size (#)	140/170	170/200	200/230	270/300	325/400
Surface roughness (μm)	0.653	0.598	0.595	0.586	0.554

The results of the study show that the roughness of the silicon nitride surface decreases with decreasing diamond abrasive particle size while keeping other conditions constant. As the diamond abrasive grain size decreases, the height of the abrasive grain protrusion on the grinding wheel also becomes smaller, resulting in a decrease in the average height of the abrasive grain grinding blade. As a result, the density of abrasive grains in the grinding wheel of the grinding wheel increases, and the number of abrasive grains participating in grinding per unit area increases. In this case, the wear scar on the surface of the silicon nitride becomes shallower and thinner, and the average grinding force per abrasive grain is reduced, so that the grinding rate of the silicon nitride ceramic is reduced, and the surface roughness of the workpiece is also reduced.

3.5. The effect of different diamond grinding wheel feed on surface roughness of silicon nitride ceramics

The three-dimensional simulation of surface image of silicon nitride ceramics under different diamond grinding wheel feed quantities was shown in Fig.5 and the surface roughness value of different grinding wheel feed quantities was listed in Table5. From Fig.5 and Table 5, it can be concluded that the surface roughness of the silicon nitride ceramic can reach 0.8 μm or less after grinding with different feed quantities. As the feed quantity decreases, the surface roughness decreases from 0.577 μm to 0.315 μm, so the surface quality is improved. At the same time, the mean variance of the surface roughness gradually decreases, and the quality of the surface gradually becomes better. Since grinding of the grinding wheel and the workpiece are in elastic contact and sliding during initial grinding, as the quantity of feed decreases, the number of micro-cracks in the sliding of the diamond abrasive in the silicon nitride ceramic decreases, then the surface roughness value of the silicon nitride gradually decreases.

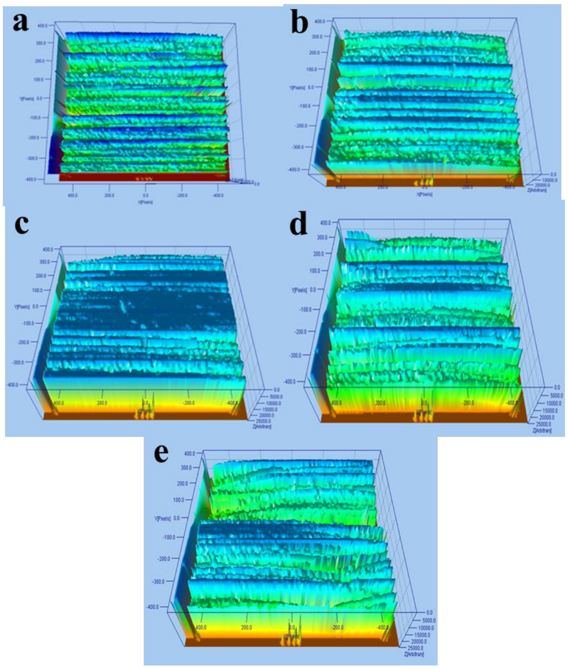

Fig.5. The three-dimensional simulation of surface image of silicon nitride ceramics under different diamond grinding wheel feed quantities.

Table5 Roughness value of the silicon nitride silicon with different grinding wheel feed quantities.

Parameters	Contents				
Feed quantity (mm)	0.02	0.03	0.06	0.09	0.12
Surface roughness (μm)	0.315	0.431	0.549	0.573	0.577
Mean variance (μm)	0.402	0.557	0.694	0.717	0.685

4. Conclusions

The virtrified bond diamond grinding wheel has the characteristics of high efficiency and low processing cost, and is an effective tool for processing silicon nitride ceramic materials.

The experimental results show that with the increase of the wheel line speed, the removal rate of grinding gradually increases. When the grinding wheel line speed is maintained at 40m/s, the grinding rate of silicon nitride increases from 0.0674g/min to 0.4528g/min as the diamond abrasive grain size increases from 325/400 to 140/170. As the diamond abrasive grain size decreases, the machined surface roughness decreases from 0.653 μm to 0.554 μm. With the increase of wheel line speed, the roughness of the machined surface decreases from 1.212μm to 0.814μm. As the feed quantity of grinding wheel decreases from 0.12mm to 0.02mm, the surface roughness of silicon nitride ceramic decreases from 0.577μm to 0.315μm.

The process of grinding the silicon nitride ceramics with virtified bond diamond grinding wheel is mainly divided into rough grinding stage and fine grinding stage. By controlling the feed quantities amount, both stages can be accomplished with the same grinding wheel. In the rough grinding stage, the grinding wheel feed is 0.12mm, which can remove 90% of the amount to be processed. In the fine grinding stage, the grinding wheel feed amount is 0.02mm, and the remaining machining amount is removed under the requirement of the workpiece size.

Acknowledgments

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