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Study on Ultrasonic Vibration Grinding Character of Nano ZrO_2 Ceramics

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Keywords: nano ZrO_2 ceramics； ultrasonic grinding； grinding forces； surface quality； critical ductile grinding depth.

Abstract. Nano ceramics possessed ascendant mechanical property and physical characteristics contrast with engineering ceramics, so it has extensive application prospect in various industries. On the basis of applying the indentation fracture mechanics to analyze the removal mechanics of ceramic material, this paper analyzed the critical ductile grinding depth of the nano ZrO_2 ceramics. Adopting ultrasonic composite processing we describe the influence of different processing parameters and grain size of diamond wheel on the grinding forces and surface roughness. Based on the grinding forces and surface roughness the grinding process with and without vibration is analyzed. By means of SEM and AFM the surface character and critical ductile grinding depth of nano ZrO_2 ceramics are also discussed. The paper supplied the theoretical and experimental basis for the grinding of the large-sized ultraprecision plate structure of nano ZrO_2 ceramics (nm).

Introduction

Engineering ceramics that are also called structure ceramics have been applied widely because they have the merits of high hardness, resistant to high temperature, resistant to abrasion, resistant to erosion, light quality and good conduction of heat. But engineering ceramics has some shortages such as large brittle, bad uniform, low reliability, less malleable and intensity etc, so their application is limited. With the wide application of nano technology, nano ceramics come forth and have the flexibility and machinability to overcome the brittleness of ceramics materials. English scholar Cahn[1] pointed out that nano ceramics were the strategic path to overcome the brittleness of ceramics. Nano ceramics materials obtained by nano technology are that their crystal grain, grain boundary and their bonding are at the nano level(1—100nm) among the microstructure of ceramics materials. Because of the refinement of nano ceramics grain, the number of their grain boundary increases greatly to increase the intensity, malleability and superplasticity of materials greatly and overcome many shortages of engineering ceramics and have the great effect on the mechanical property, electrical performance, thermal performance, magnetic performance and optical performance of materials[1-2]. In order that nano ceramics is used in the production to obtain the nano surface as soon as possible, we must carry out the grinding mechanics study on nano ceramics. This paper has studied the critical grinding depth, the grinding force and the surface quality of nano ZrO_2 ceramics by the use of the compound technology of the ultrasonic vibration grinding and common grinding.

The study on the critical ductile grinding depth of ZrO_2 ceramics

According to the study, the removal mechanics of the ceramics material is similar to metal when the grinding depth less than critical value. The ductile grinding is generally defined as the fracture rate of the grinding surface is less than 10%. According to the research findings of Marshall and Lawn[3], T.G.Bifano[4] built up the formula of the critical cutting depth of the brittle material by the use of the micro indentation method.

$$d_c = \xi\left(\frac{E}{H}\right)\left(\frac{K_C}{H}\right)^2, \qquad (1)$$

Here: H — Vickers hardness; E —elasticity modulus; Kc— fracture toughness; ξ — the coefficient of different materials.

According to the experiments, ξ is chosen as 0.15 for the general hard brittle material. When the grinding depth ap is less than dc, the hard brittle material may carry out the plastic grinding.

Because the nano ZrO_2 ceramics has the larger superplastic property than the general hard brittle material, its deformation mechanism is that grain boundary slip, particles rearrange and the fracture way is mostly transgranular fracture. Its critical ductile grinding depth not only connected with character of material and processing method but also have some relation with the geometric parameters of cutting lip, the grinding speed, the cutting-in of grain and grinding fluid. So the value of ξ for general brittle material is not suitable for the nano ceramics material (ZrO_2).

According to the above analysis ξ in formula (1) could be modified as:

$$\xi = \{\xi_1, \xi_2, \xi_3\}, \qquad (2)$$

So formula (1) could be expressed as:

$$d_c = \{\xi_1, \xi_2, \xi_3\}\left(\frac{E}{H}\right)\left(\frac{K_C}{H}\right)^2, \qquad (3)$$

Here: ξ_1— the coefficient relate to materials.(such as general hard brittle material and nano material etc).

ξ_2 —the coefficient relate to processing method.(such as ultrasonic processing, electromachining, photoetching machining and chemical machining etc)

ξ_3— the coefficient relate to processing parameters.(such as geometric parameters of cutting lip, the grinding speed, the cutting-in of grain and grinding fluid etc)

The other symbols the same with formula (1).

The experiment conditions and experiment method

Figure .1 is the device of the experiment, and the character of nano ZrO_2 ceramics is shown in Table 1.The grinding machine was M6025C multipurpose instrument grinder. The values of surface roughness were averaged from six points normal to groove mark of the surface with JJ1-B contact stylus roughness instrument. The microstructure of surface was observed by SEM and AFM. The ultrasonic vibration was automatically controlled around a frequency of f=20 KHz and the amplitude of vibration was hold at A=12μm .The diamond wheels were dressed(profiled #200SiC, sharpened #400Al_2O_3) with grindstone block. During the dressing of wheels which speed of wheel are 35.3m/s, and grinding depth are 10μm/pass. When the ultrasonic generator is opened, it is ultrasonic grinding, and when the ultrasonic generator is closed, it is the common grinding.

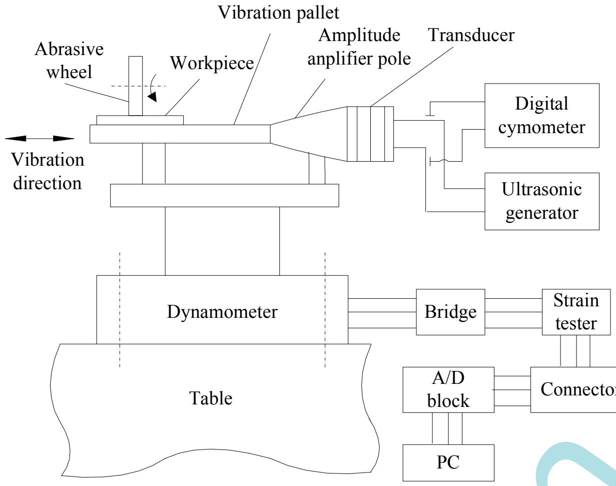


Fig. 1 The device of the experiment

Table 1 The characters of nano ZrO_2 ceramics

The index of the material performance	value
The Vickers hardness [Gpa]	12
The elasticity modulus [Gpa]	360
The bending strength [Mpa]	700
The fracture toughness [Mpa.m$^{1/2}$]	9.3
The density [g/cm^3]	6.2
The Poisson's ratio [v]	0.27
The coefficient of thermal conductivity [W/m·K]	30
The grain size of material [nm]	60

The experimental research of the critical grinding depth

The SEM photos of nano ZrO_2 brittle grinding is shown in Figure 2. From the figure, we can see that the surface of grinding is in the completely broken state at this moment. The state of the critical ductile grinding is shown in Figure 3, the percentage of damage surface is from 10% to 15%, and grinding depth is $15\mu m$. The state of ductile grinding of material is shown in Figure 4, the surface's groove mark of material is uniform, and the surface almost have no broken phenomenon. In the state of ultrasonic grinding, the ductile grinding depth of nano ZrO_2 ceramics is higher than that of common grinding, as shown in figure 5, the grinding depth is $15\mu m$, at this moment it is also the ductile grinding. From the figure, we can see that its grinding groove is deeper than that of common grinding, and its groove width is even, it is because that its ultrasonic vibration direction and its grinding force reduce under the ultrasonic vibration grinding. During the experiment, the critical ductile grinding depth of nano ZrO_2 ceramics is about $15\mu m$ under common grinding and $25\mu m$ under ultrasonic vibration grinding. This experiment has proved that theoretical critical grinding depth have some relation with other factors besides characters of materials and cutting parameter. Specially, the processing method must be considered, such as ultrasonic compound machining which remove material with high energy. The consider factor of ξ_2 possible relate to the change of constitutive in interior of material, that is the change of E and H. This issue need more thorough research in future.

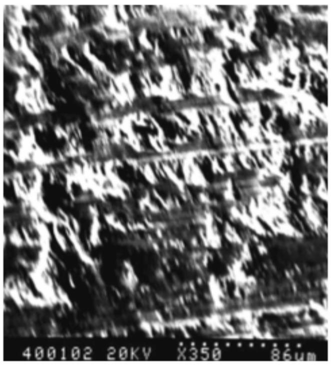


Fig.2 the brittle grinding surface
a_p=20μm/pass, common grinding

Fig.3 the critical grinding surface
a_p=15μm/pass, common grinding

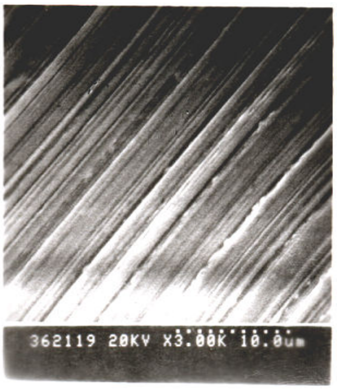


Fig.4 the ductile grinding surface
a_p=10μm/pass, common grinding

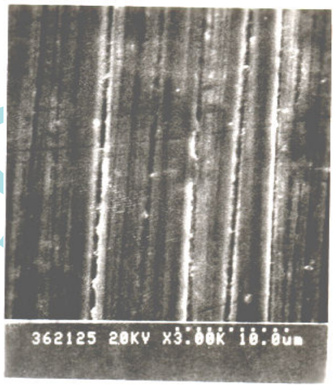


Fig.5 the ductile grinding surface
a_p=15μm/pass, vibration grinding A=12μm

The experimental research of the grinding force and surface quality

The effect of wheel speed. From the figure 6 and figure 7, the effect of the wheel speed on the grinding force and surface quality are as follows:

1. During the common grinding, the grinding forces of normal direction and tangential direction tend to reduction with increasing of wheel speed. The normal force reduces quickly and tangential force changes very slowly with increasing of wheel speed. During the ultrasonic vibration grinding, the normal force and tangential force have not changed remarkably;
2. Whether it is the normal force or the tangential force, the grinding force of ultrasonic grinding is lower than common grinding force;
3. The roughness of grinding surface tends to reduce when the linear speed of the wheel increases;
4. The wheel linear speed has a great influence on surface roughness in common grinding. While in ultrasonic vibration grinding, it influences on surface roughness not so strong as in common grinding.

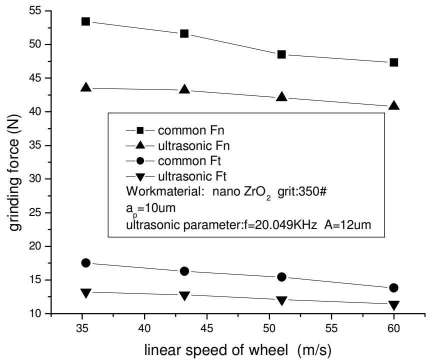


Fig 6 the effect of the wheel velocity on the grinding force

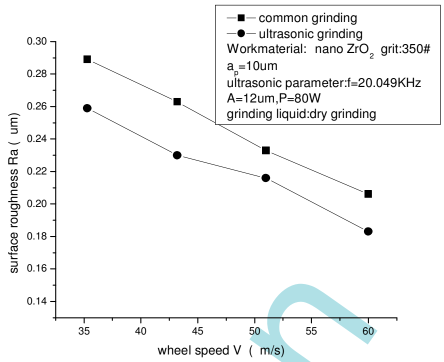
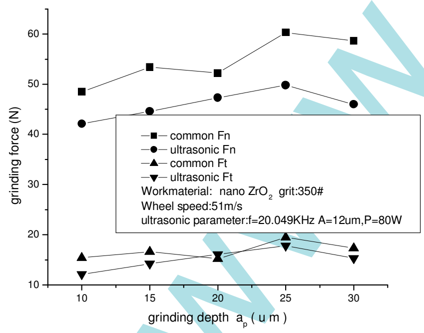


Fig 7 the effect of the wheel velocity on the surface quality

The effect of grinding depth. In figure 8 and figure 9, the variation of grinding force and surface roughness with grinding depth are presented. As shown in figure, grinding force increases sharply with the increase of grinding depth. In common grinding, grinding force reaches maximum and then trends to reduce when grinding depth reaches 15 μm/pass. Later, grinding force shows the phenomenon of fluctuation. Critical grinding state of the material can be judged at this moment through the preceding experiment. It shows the same phenomenon in ultrasonic vibration grinding as in common grinding. But it appears similar unstable grinding states until grinding depth up to 25μm/pass. So can find out its critical depth is deeper than common grinding depth.

In addition, whatever normal grinding force or tangential grinding force, its grinding force in ultrasonic vibration grinding is obviously lower than ordinary grinding.

With the increase of grinding depth, the surface roughness of common and ultrasonic vibration grinding all have increscent trend, but, the surface roughness will not increase very quickly under the critical ductile grinding depth. The surface roughness increase dramatically over critical grinding depth, which indicates the critical ductile grinding depth of ultrasonic vibration grinding is greater than that of common grinding.



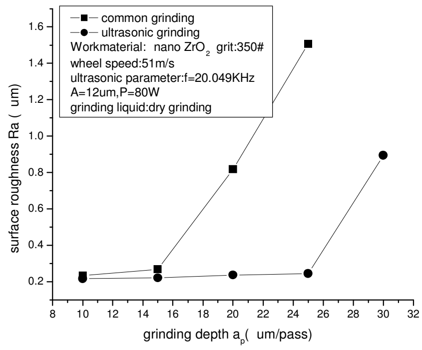


Fig.8 the effect of the grinding depth on the grinding force

Fig.9 the effect of the grinding depth on the surface quality

The effect of the no-spark grinding times. Figure 10 shows that the surface of nano ZrO_2 ceramics has obtained the level of nanometer after ultrasonic vibration grinding. The value of surface roughness Ra is about 70 nm by the measurement of AFM. From figure 11, the surface sharp peaks lessening obviously and the channel mark being narrower and fleeter after no-spark grinding for 10 times, and its surface roughness Ra is about 60 nm.

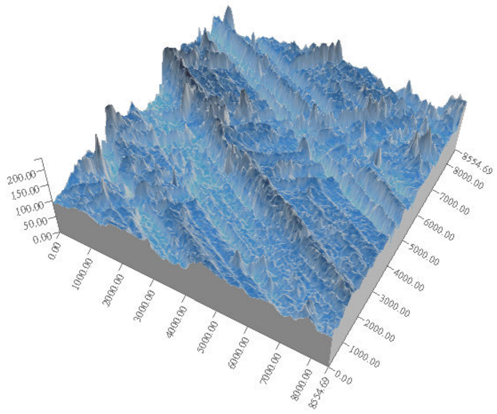


Fig.10 the AFM photo after ultrasonic vibration grinding (coordinate unit: nm)

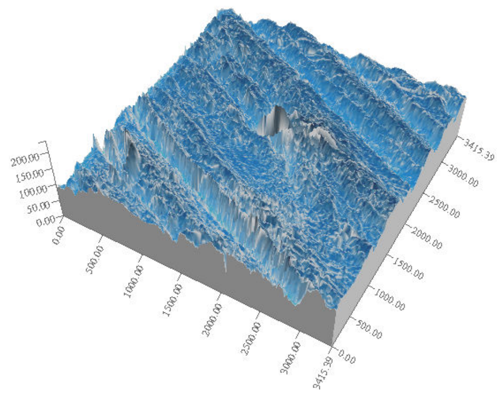


Fig.11 the AFM photo after no-spark ultrasonic vibration grinding (coordinate unit: nm)

Summary

1、Because of the superplasticity of nano ZrO_2 ceramics, its critical ductile grinding depth can not simply use original critical grinding formula. The value of ζ is related to the characters of material , processing parameters and the processing method. When grinding ZrO_2 ceramics by ultrasonic vibration, the value of ζ is possible much more than 0.15.

2、From experiment it is found that actual critical grinding depth is larger than theoretical critical grinding depth, the critical grinding depth of nano ZrO_2 ceramics in ultrasonic vibration grinding is about 25 μ m, but in common grinding it is about 15 μ m.

3、Increasing linear velocity of grinding wheel can properly reduce grinding force and surface roughness. But excessive velocity can also create the oscillation of machine tool.

4、Over critical ductile grinding depth of the workpiece, the grinding force will decrease, then bouncing phenomenon appears, over critical ductile grinding depth ,the value of surface roughness will dramatically increase. Because of the larger critical ductile grinding depth in ultrasonic vibration grinding, the productivity will dramatically increase by use of ultrasonic vibration for the same surface quality.

5、Because of the elastane of the shaft system and the grinding wheel, in order to obtain the ideal surface roughness, the workpiece must be no-spark grinded for 6—10 times optimally.

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