Ultra-Smoothness Grinding of Fine Ceramics with #140-Mesh Grain Size Diamond Wheel

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1. Introduction

Grinding operation is one of the most effective manners for high smoothness machining of fine ceramics. It is difficult, however, to form crack-free high smoothness surface by ductile-mode grinding because of their mechanical properties of high brittleness [1]. Then it is necessary for ductile-mode grinding that the suitable grinding conditions are selected. Some reports [2], [3] concerning ductile-mode grinding have been done with the wheel of finer grain size than #1500-mesh. But the truing and dressing technics for the fine grain size wheel are difficult. In addition, the depth of cut and/or table speed are also limited to a certain small range because the active grain is thrown off easily from the wheel surface by small grinding force.

Therefore, in our previous researches [4]-[6], the adaptation of the coarse #140-mesh grain size wheel to the ductile-mode grinding of silicon carbide ceramic was investigated experimentally in the surface plunge grinding and found to be possible. The surface roughness in the surface plunge grinding, however, is limited to about 200nm(Rmax) because of the formation of the grinding grooves.

In this research, the effect of the newly devised ultra-smoothness grinding method, in which the grinding grooves can be removed and diminished, is examined experimentally by grinding fine ceramics with the coarse #140-mesh diamond wheel. From the result, it is found that the formed surface roughness is attainable below about 10nm(P-V) and 1nm(RMS) for the hot pressed silicon carbide.

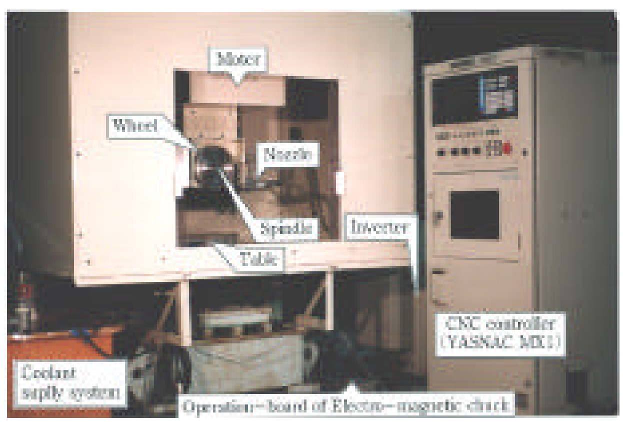

Fig.1 Appearance of NC grinding machine

2. Experimental procedure

The experiments are carried out with the NC grinding machine as shown photographically in Fig.1. The machine is reconstructed of a conventional NC equipment which has the accuracy of 1μm for each movement of the X, Y and Z direction. The newly devised ultra-smoothness grinding method is shown schematically in Fig.2. In the method, the workpiece is fed simultaneously toward the both directions normal and parallel to grinding direction. The method is different from the usual traverse surface grinding method in which the cross-feed normal to grinding direction is done after grinding the whole width of workpiece in a pass or stroke of table. However the cross-feed $(v_w)_n$ normal

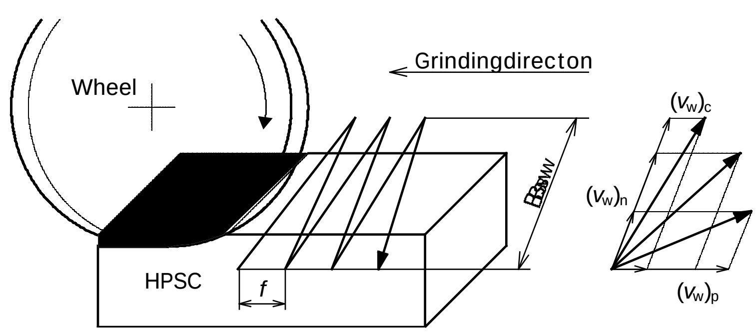

Fig.2 Ultra-smoothness grinding method

to grinding direction is faster than plunge-feed $(v_w)_p$ parallel to grinding direction. In the experiments, the $(v_w)_n$ and $(v_w)_p$ are set by determining the resultant feed $(v_w)_c = \{(v_w)_n + (v_w)_p\}^{1/2}$, the cross-feed width *B*sw and the feed width *f*.

The experimental conditions are summarized in Table 1. The grain size and concentration of the wheel used are #140-mesh and 50, respectively. The fine ceramics used are the hot pressed silicon carbide (HPSC), the hot isostatic pressed silicon nitride (HIPSN) and the alumina-titanium carbide (Al_2O_3-TiC). The observation and roughness measurement of the ground workpiece surface are done with Nomarski microscope and SEM, and with the surface interferometer (WYKO TOPO-3D) and AFM (NanoScope III), respectively.

Table 1 Experimental conditions

Grinding method	Ultra smoothness
Wheel	SD140Q50M
Workpiece	Hot pressed silicon carbide Hot isostatic pressed silicon nitride, Alumina -titanium carbide
Wheel speed	v_g = 20 mm/s
Resultant feed	$(v_w)_c$ = 0.833 mm/s, 3.33 mm/s
Crossfeed width	Bsw = 18 mm
Plunge feed	f = 20ìm/stroke
Depth of cut	t_t = 2ìm
Coolant	Soluble (1/50) Flow rate : 12 L/min

3. Results and discussions

3.1. Ductile-mode grinding of fine ceramics with #140-mesh diamond wheel

Figure 3 shows the microscope photographs of the Al_2O_3-TiC surfaces plunge-ground at $(v_w)_p$=0.05mm/s and $(v_w)_p$=0.005mm/s under the wheel speed of V_g=20m/s with the #140-mesh diamond wheel. From the figure, the grinding cracks along with the ductile-mode grinding area are observed on the workpiece surface ground at $(v_w)_p$=0.5mm/s. At the extremely slow table speed of $(v_w)_p$=0.005 mm/s, on the other hand, the ductile-mode ground surface without grinding cracks is obtained all over the whole observed workpiece area. However the whole ground workpiece area of 10mm square observed widely is also confirmed to consist of ductile-mode ground surface. Accordingly the grinding cracks are considered to decrease with the decrease of table speed.

A WYKO 3D image of 256μm square surface of Al_2O_3-TiC ceramic plunge-ground at v_w=0.005mm/s is shown in Fig.4. From the figure, it is found that the grinding grooves parallel to grinding direction are observed on the surface. The height and pitch of grinding groove are about 400nm(P-V) and below about 100μm, respectively. The height is closely related to the maximum surface roughness. The similar results are obtained for HPSC ceramic and HIPSN ceramic.

Accordingly the ductile-mode grinding of fine ceramics with the #140-mesh wheel of the low concentration of 50 is possible in the surface plunge grinding with a conventional surface grinder. It is considered that the problem for the formation of ultra-smoothness is the high grinding grooves.

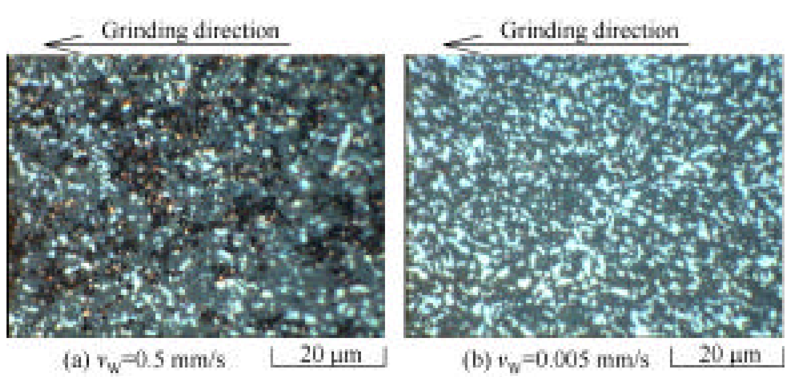

Fig.3 Microscopic photographs of the Al_2O_3-TiC ceramic surfaces plunge-ground at $(v_w)_p$=0.5mm/s and $(v_w)_p$ =0.005mm/s with the #140-mesh wheel
[SD140Q50M, Vg=20m/s, t_t=2μm, Soluble (1/50)]

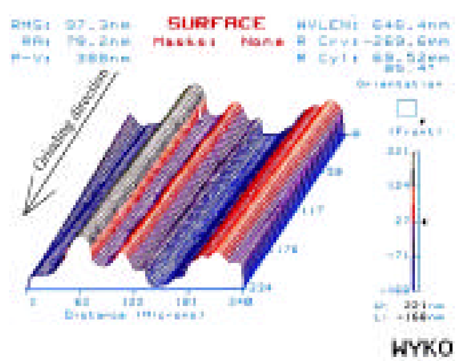

Fig.4 3D image of the Al_2O_3-TiC ceramic surface plunge-ground at $(v_w)_p$=0.005mm/s with the #140-mesh wheel
[SD140Q50M, *V*g=20m/s, t_t=2μm, Soluble (1/50)]

3.2. Ultra-smoothness grinding of fine ceramics with #140-mesh diamond wheel

Figure 5 shows the WYKO 3D image along with microscopic photograph of the Al_2O_3-TiC ceramic surface ground at $(v_w)_c$ =0.83mm/s by ultra-smoothness grinding method with the #140-mesh wheel. From the photograph, a few of grinding cracks can be found on the observed workpiece area. But it is obvious from the WYKO 3D image that the workpiece surface is not formed by continuous regular grinding grooves found in plunge-grinding as shown in Fig.4, but some discontinuous short grinding grooves. The 3D surface roughness of 256μm square surface, which is much better than that formed by plunge-grinding is about 28nm(P-V)s, 4.7nm(RMS)s and 3.8nm(Ra)s. Accordingly the grinding grooves are considered to be removed to large extent.

Figure 6 shows AFM 3D images and 2D profiles of 50μm square surface of HPSC, HIPSN and Al_2O_3-TiC ceramics ground at $(v_w)_c$=3.33mm/s. The upper and lower 2D profiles are measured for the direction parallel and normal to grinding direction, respectively. The obvious micro-hole can be hardly found on the 3D image of the HPSC ceramic surface. From the 2D profiles the surface roughness parallel to grinding direction is about 3.8nm(Rmax)p and 0.91nm(RMS)p for excluding micro-holes. The surface roughness normal to grinding direction is about 5.3nm(Rmax)n for excluding the micro-hole and 54nm(Rmax)p for including the deepest micro-hole.

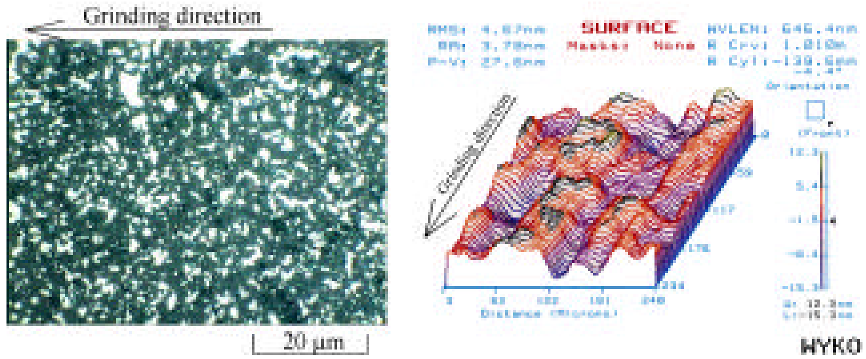

Fig.5 WYKO 3D image with microscopic photograph of the Al_2O_3-TiC ceramic surface ground at $(v_w)_c$=0.83mm/s by ultra-smoothness grinding method with the #140-mesh wheel
[SD140Q50M, Vg=2m/s, t_t=2μm, Soluble (1 /50)]

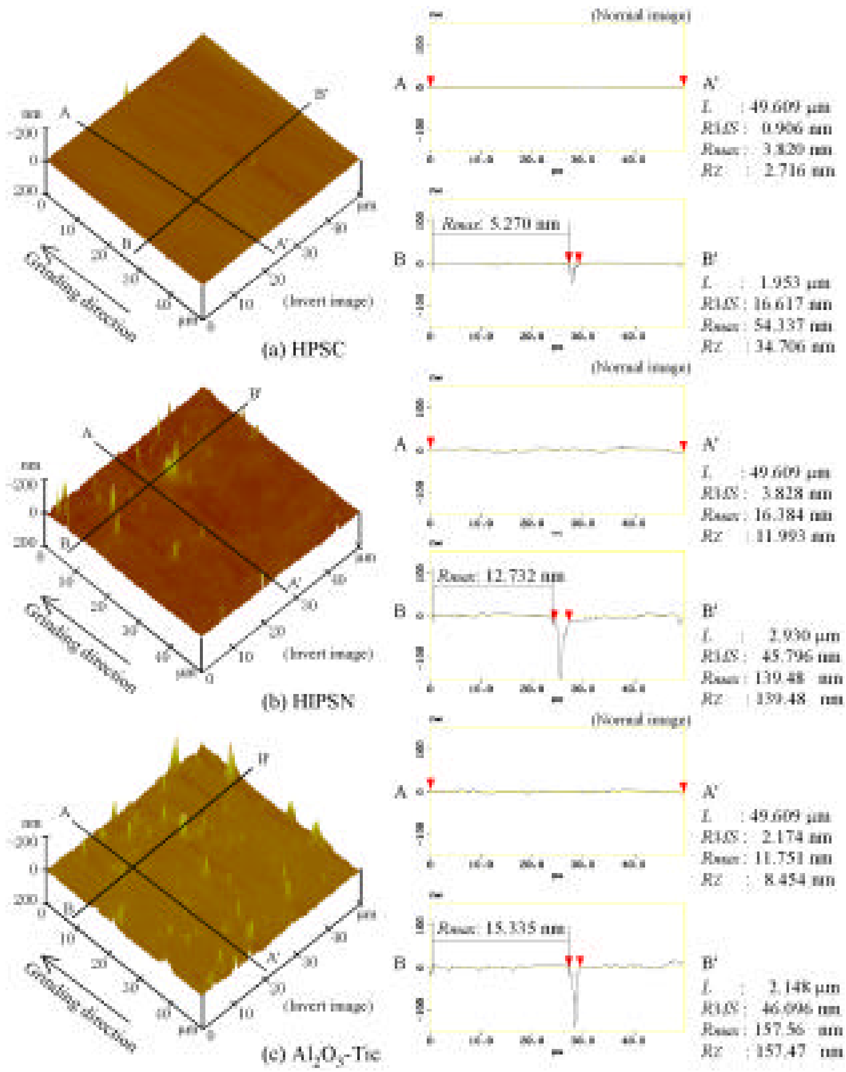

Fig.6 AFM images of fine ceramic surfaces ground at $(v_w)_c$=3.33mm/s by ultra-smoothness grinding method with the #140-mesh wheel
[SD140Q50M, *V*g=20m/s, t_t=2μm, Soluble (1/50)]

For the HIPSN and Al_2O_3-TiC ceramics, on the other hand, a lot of micro-holes are found on the ground surface. The surface roughnesses parallel and normal to grinding direction for HIPSN ceramic are about 16.3nm(Rmax)p and 3.8nm(RMS)p for excluding micro-holes, and about 12.7nm(Rmax)n for excluding micro-holes and 140nm(Rmax)n for including a micro-hole, respectively. The surface roughnesses parallel and normal to grinding direction for Al_2O_3-TiC ceramic are about 11.8nm(Rmax)p and 2.1nm(RMS)p for excluding micro-holes, and about 15.3nm(Rmax)n for excluding micro-holes and 158nm(Rmax)n for including a micro-hole, respectively.

It is considered from these results that the suitable ultra-smoothness grinding conditions depend on the characteristics of fine ceramics. In this research, the suitable conditions are not found for ultra-smoothness grinding of various kinds of fine ceramics. However, it is reasonable to say that the newly devised ultra-smoothness grinding method is effective for the formation of ultra-smoothness surface by grinding fine ceramics with the coarse #140-mesh diamond wheel.

4. Summary

The ductile-mode grinding of fine ceramics of the hot pressed silicon carbide (HPSC), the hot isostatic pressed silicon nitride (HIPSN) and the alumina-titanium carbide (Al_2O_3-TiC) with the coarse #140-mesh metal-bonded diamond wheel is found to be possible in the surface plunge grinding. The surface roughness in the ductile-mode plunge grinding, however, is rough over 200nm(Rmax) because of the formation of the grinding grooves. The newly devised ultra-smoothness grinding method in which the grinding grooves can be removed and diminished is effective for the formation of ultra-smoothness surface on the fine ceramics. When using the new method, the surface roughness of the ground hot pressed silicon carbide ceramic area of 50μm square measured with AFM is attainable about 3.8nm(Rmax) and 0.91nm(RMS).

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