Influence of Fluid Supply on Ultra-smoothness Grinding of Silicon Nitride Ceramic with #140 Metal Bond Diamond Wheel

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1. Introduction
Grinding operation is one of the most effective manners for high smoothness machining of fine ceramics. However, it is difficult to form crack-free high smoothness surface by ductile-mode grinding because of their mechanical properties of high brittleness. To machine the ceramic component of high quality by low productive cost, the high productive ultra-smoothness grinding technique for the fine ceramics has been strongly required. In our previous researches1),2), the new ultra-smoothness grinding method is developed and ascertained to be useful for finishing to near the ultra-smoothness surface. The surface roughness of silicon carbide ceramic and cemented carbide tool formed by the ultra-smoothness grinding method using the #140 diamond wheel is found to attain below 25nm($R_z$) or 4nm($R_a$), and below 30nm($R_z$) or 5nm($R_a$), respectively.

This is one of a series of the researches on ultra-smoothness grinding of fine ceramics. In this report, the influence of grinding fluid supply on ultra-smoothness grinding of silicon nitride ceramic (HIPS N) is examined.

2. Ultra-smoothness grinding method
In the previous research1), the possibility of the high removal rate ultra-smoothness grinding method which can finish to almost the same smoothness formed by polishing is examined using traverse grinding. It is found from the results that the smoothness, which can be attained by traverse grinding, is limited roughly over the critical surface roughness because of the occurrence of rough grinding groove parallel to grinding direction formed by grinding.

To diminish the groove, the newly devised ultra-smoothness grinding method1) is proposed as shown in Fig.1 and ascertained to be useful for finishing near the ultra-smoothness surface. First of all, in the new method, the workpiece-wheel contact width is ground by feeding the workpiece toward the direction normal to grinding direction. As shown in Fig.2, in the grinding process, the feed per a wheel revolution $f_{Gn}$ is smaller than the wear width of cutting edge $w_n$, normal to grinding direction. In the second step, the workpiece is slightly step-fed the length of $f_p$ parallel to grinding direction so that the geometrical surface roughness, $H_p$, formed by overlapping cross-sections of two wheel circles before and after the step-feed becomes smoother than the required surface roughness. Then the workpiece-wheel contact width is ground again by feeding reversibly the workpiece toward the direction normal to grinding direction. By repeating such a grinding procedure, the whole surface of workpiece is finished.

3. Experiments
The experiments are carried out with the NC grinder as shown photographically in Fig.3. The grinder having air spindle has the accuracy of 0.1µm for each movement of the X, Y and Z direction. The experimental conditions are summarized in Table 1. The grain size and concentration of the wheel used are #140 and 50,
respectively. The hot isostatic pressed silicon nitride (HIPSN) is used as the workpiece of fine ceramic. All the grinding fluids are soluble type. Type T1 includes a plenty of anionic surfactant. Type T2 includes a plenty of fatty acid and a little ester and glycol. Type T3 includes a plenty of glycerin. 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), respectively.

4. Results and discussions
4.1 Influence of grinding fluid type on ductile-mode plunge grinding

Figure 4 shows the micrographs and SEM photographs of the HIPSN surface formed by plunge grinding with the #140 diamond wheel at \( v_{wp} = 0.01 \text{mm/s} \) under the wheel speed of \( V_g = 20 \text{m/s} \) in dry grinding and wet grinding. In wet grinding, three types of grinding fluids are used. The grinding condition is shown in the figure. In case of dry grinding, from the figure, grinding grooves together with a plenty of large cracks formed by brittle-mode grinding are observed on the workpiece surface. And also, the surface topography like melted surface layer is observed on the workpiece surface. In case of wet grinding, on the other hand, the grinding grooves are observed similar to dry grinding. But the grooves are less and smoother than dry grinding. And also, most of the ground surface is formed by ductile-mode grinding. In wet grinding, however, the surface smoothness depends on grinding fluid type. When using fluid type T1, the smooth ductile-mode surface is found all over the workpiece surface. When using fluid type T2 and T3, on the other hand, the ductile-mode surfaces with some grinding cracks are observed on the workpiece surface. It is considered from these results that grinding fluid type has strong influence on ductile-mode grinding of fine ceramics. As the grinding grooves parallel to grinding direction in the
plunge grinding method are formed roughly on the surface, it is difficult to finish to the ultra-smoothness surface\(^1\).

4.2 Influence of grinding fluid type on ultra-smoothness grinding

Figure 5 shows the micrographs and SEM photographs of the HIPSN surface formed by ultra-smoothness grinding method using three types of grinding fluids. It is found from the figure that, for all the fluid type, the smooth ductile-mode surface without grinding grooves is obtained on the workpiece. Especially, when using fluid type T1, the ultra-smoothness surface without grinding cracks is observed as well as the result of HPSC as reported previously\(^2\). When using fluid type T2 and T3, however, the some grinding crack are formed on the ground workpiece surface. From the results, it is referred that the suitable grinding fluid is important to be selected for the ultra-smoothness surface of HIPSN.

4.3 Influence of grinding fluid dilution on ultra-smoothness grinding

Figure 6 shows the comparison of HIPSN surfaces ground by ultra-smoothness grinding using the grinding fluid diluted at 10 times, 50times, 100 times and only water. Grinding fluid used is the type T1, which gives the best result in Fig.5. In case of 10 times and 50 times, as seen from the figure, some grinding cracks are observed on the ground workpiece surface. In cases of 100 times, on the other hand, the grinding cracks are hardly observed. In case of only water, the generated grinding cracks are a little.
Figure 7 shows the relationship between HIPSN surface roughness and dilution degree of grinding fluid. For the reference, the same relationship for HPSC\(^2\) is also shown in the figure. In case of HIPSN, the surface roughness is the worst at dilution degree of 10 times. And, the surface roughness becomes smoother as grinding fluid is diluted higher to 100 times. In case of only water, however, the surface roughness becomes somewhat rougher than that in case of 100 times. From the results, the dilution of grinding fluid is considered to have strong influence on the surface roughness in ultra-smoothness grinding.

Figure 8 shows a WYKO 3D image and 2D profiles of 256\(\mu\)m square of HIPSN surface formed by ultra-smoothness grinding using the grinding fluid type T1 diluted at 100 times. It is found from the figure that the 3D surface roughness is about 57nm\(\left(R_z\right)\) or 2.7nm\(\left(R_a\right)\) and the 2D surface roughness parallel and normal to grinding direction is about 11nm\(\left(R_z\right)\) or 1.5nm\(\left(R_a\right)\) and about 13nm\(\left(R_z\right)\) or 2.1nm\(\left(R_a\right)\), respectively. Such a high smooth surface roughness is near the surface roughness formed by lapping or polishing.

5. Summary

Using the newly developed ultra-smoothness grinding method, the influence of the grinding fluid supply on the ultra-smoothness grinding of silicon nitride ceramic (HIPSN) is examined. The main results obtained are as follows:

1. Grinding fluid supply is necessary for the ultra-smoothness grinding of silicon nitride ceramic. In case of dry grinding, the surface topography like melted surface layer is observed on the workpiece surface.
2. The type and dilution of grinding fluid have the strong influence on the surface roughness in ultra-smoothness grinding of silicon nitride ceramic.
3. The 3D and 2D surface roughnesses of silicon nitride ceramic formed by the newly developed ultra-smoothness grinding method with the suitable grinding condition attain about 57nm\(\left(R_z\right)\) or 2.7nm\(\left(R_a\right)\), and about 12nm\(\left(R_z\right)\) or 2.0nm\(\left(R_a\right)\), respectively.

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References