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 research, the newly devised ultra-smoothness grinding method is proposed 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(Rz) or 4nm(Ra), and below 30nm(Rz) or 5nm(Ra), respectively.

This is one of a series of the researches on ultra-smoothness grinding of fine ceramics. In this report, the effect of the grinding fluid supply on ultra-smoothness grinding of silicon carbide ceramic is examined.

2. Ultra-smoothness grinding method

In our previous research, 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 to over the critical surface roughness because of the occurrence of grinding groove parallel to grinding direction formed by grinding. On the basis of the results, the newly devised ultra-smoothness grinding method is proposed as shown in Fig.1 and ascertained to be useful for finishing to 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, the feed per a wheel revolution, $f_{on}$, is smaller than the wear width of cutting edge, $w_n$, normal to grinding direction. In the second step, after the workpiece is slightly step-fed to the length of $f_p$ parallel to grinding direction so that the geometrical surface roughness formed by overlapping the cross-section of two wheel circles before and after the step-feed becomes smoother than the required surface roughness, the workpiece-wheel contact width is ground again by feeding reversely the...
workpiece toward the direction normal to grinding direction. The whole surface of workpiece is finished by repeating such a grinding procedure.

3. Experiments

The experiments are carried out with the NC grinder as shown photographically in Fig.3. The grinder using air spindle has the accuracy of 0.1 µm 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 #40 and 50, respectively. The hot pressed silicon carbide (HPSC) is used as the workpiece of fine ceramic. All of 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 Effect of grinding fluid supply

Figure 4 shows the microscope and SEM photographs of the HPSC surfaces formed by ultra-smoothness grinding in dry grinding and wet grinding. The grinding condition is shown in the Figure. From the figure, it can be confirmed that the grinding grooves observed in traverse grinding can't be observed on both of dry and wet ground surfaces. In dry grinding, however, the surface
topography like melted surface layer is observed on the workpiece surface. In the wet grinding, on the other hand, the smooth ductile-mode ground surface without grinding cracks is obtained all over the whole workpiece.

Figure 5 shows WYKO 3D images and 2D profiles of 256 µm square surface of HPSC ceramics formed by dry and wet ultra-smoothness grinding. In case of the dry grinding, the 3D surface roughness is about 1.3 µm(Rz) or 92 nm(Ra). From the 2D profiles, the 2D surface roughness parallel to grinding direction is about 333 nm(Rz) or 61 nm(Ra). And also the 2D surface roughness normal to grinding direction is about 463 nm(Rz) or 84 nm(Ra). In case of the wet grinding, on the other hand, the 3D surface roughness is about 47 nm(Rz) or 2.4 nm(Ra). Both of the 2D surface roughness parallel and normal to grinding direction are about 10 nm(Rz) or 2.0 nm(Ra). The smoothness in wet ultra-smoothness grinding is found much better than dry grinding. It is considered from these results that grinding fluid supply has large influence on the workpiece surface formed by ductile-mode ultra-smoothness grinding.

In Figure 6, the Vickers hardness of the workpiece surface layer formed by dry grinding and wet grinding is compared. For the comparison, the Vickers hardness by polishing is also shown in the figure. From the results, the hardness formed by both of dry grinding and wet grinding is found lower than polishing. The surface layer in dry grinding is softer than wet grinding. It is considered from the result that grinding heat softens the surface layer.

4.2 Effect of grinding fluid type

In Figure 7, the HPSC surfaces formed using three types of grinding fluids are compared. The surfaces are different from type of grinding fluid. In case of fluid type T1, the ultra-smoothness surface without grinding cracks is observed. In cases of fluid type T2 and T3, the grinding crack is observed 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 grinding of fine ceramics.

4.3 Effect of grinding fluid dilution

The surface roughness of HPSC ceramic ground by ultra-smoothness grinding using the grinding fluid diluted at 10 times and 50 times is compared in Figure 8. The measuring area is 256 x 256 µm². The grinding condition
is shown in the Figure. From the result, the 3D surface roughness is almost the same smoothness of about 30nm(Rz) or about 2.4nm(Ra) in both of 10 times and 50 times dilution.

Figure 9 shows the relationship between surface roughness and dilution degree of grinding fluid. From the figure, the surface roughness for the grinding fluid of the dilution of 10 to 50 times is almost the same value. In case of the silicon carbide ceramic, the dilution degree of grinding fluid of 10 to 50 times is considered to have little influence on the surface roughness in ultra-smoothness grinding.

5. Summary
The effect of the grinding fluid supply on ultra-smoothness grinding of silicon carbide ceramic is examined. The main results obtained are as follows:
(1) Grinding fluid supply is necessary for the ultra-smoothness grinding of silicon carbide ceramic. In case of dry grinding, the surface topography like melted surface layer due to thermal softening is observed on the workpiece surface.
(2) Grinding fluid type has the strong influence on the ultra-smoothness grinding of silicon carbide ceramic. It is important to select the suitable dilution of grinding fluid for obtaining the ultra-smoothness surface.
(3) The dilution of grinding fluid has the influence on the surface roughness in ultra-smoothness grinding of silicon carbide ceramic.
(4) The 3D and 2D surface roughnesses of silicon carbide ceramic formed using the newly developed ultra-smoothness grinding method and the suitable grinding condition attain about 30nm(Rz) or 2.5nm(Ra), and about 10nm(Rz) or 1.5nm(Ra), respectively.

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References