ULTRA-SMOOTHNESS GRINDING OF CEMENTED CARBIDE USING
NEWLY DEVELOPED VERTICAL GRINDER

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INSTRUCTION
Difficult-to-cut cemented carbide is one of the most important materials. With the increase of demand of high quality of tool, components and so on, high efficient ultra-smoothness grinding method for cemented carbide has recently been required strongly. In the previous research, the ultra-smoothness grinding method is developed and applied to horizontal surface grinder. From the result, the ground surface roughness of cemented carbide attains below 50 nm ($R_z$)1).

However, the removal rate is small thought it is larger than polishing. To resolve this problem, In the research, vertical ultra-smoothness grinding method is developed. Furthermore, using newly developed vertical ultra-smoothness grinder, the grinding characteristics of cemented carbide is examined.

ULTRA-SMOOTHNESS GRINDING METHOD
The schematic diagram of ultra smoothness grinding method is shown in FIGURE 1. First of all, in the new method, the contact width of workpiece-wheel is ground by feeding the workpiece toward the direction normal to grinding direction. The normal feed per a wheel revolution, $f_{Gn}$, must be smaller than the wear width of cutting edge normal to grinding direction. The normal feed per a wheel revolution, $f_{Gn}$, must be smaller than the wear width of cutting edge normal to grinding direction.

Secondly the workpiece is slightly step-fed a small length, $f_p$, toward the direction parallel to grinding direction. The parallel step-feed, $f_p$, however, is determined so that the geometrical surface roughness, $H_p$, which is formed by overlapping the cross-section of two wheel circles before and after step-feeding becomes smoother than the required surface roughness. After the parallel step-feed, thirdly 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 grinding procedure.

INCREASING METHOD OF REMOVAL RATE
As considered from FIGURE 1, the removal rate $M$ in the ultra-smoothness grinding method is approximated as follows;

$$M = t_g 	imes f_p 	imes f_{Gn} 	imes N_g$$  (1)

where $t_g$ and $N_g$ are depth of cut and wheel revolution number. From the equation (1), there are four elements related to the removal rate.

Depth of cut, $t_g$, of the first element can not increase selfishly because it is limited below the allowance removal depth. Concerning parallel step-feed $f_p$ of the second element, the surface roughness $(H_p)_n$ formed geometrically due to $f_p$ must be smaller than the required surface roughness. The $(H_p)_n$ is expressed as follows;

$$H_p = f_p^2/(4 \times D_g)$$  (2)

where $D_g$ is wheel diameter. Accordingly the increase of $f_p$ must be below a given value decided by the equation (2). From the equation (2), the $f_p$ can be increased by making the wheel diameter larger under the same geometrical
surface roughness. Thirdly the normal feed per a wheel revolution, \( f_{Gn} \), as mentioned above, needs smaller than the wear width of active grains normal to grinding direction. Therefore, the maximum normal feed per a wheel revolution value, \( (f_{Gn})_{max} \), in the range below which the ultra-smoothness grinding is possible depends on the wear width of active grains. According to the separate experiments in the horizontal grinding method\(^3\), the \( (f_{Gn})_{max} \) is remarkably small value below 50 micro-meters. In the present state, the increase of the \( (f_{Gn})_{max} \) can not be expected for increasing the removal rate.

Finally the maximum wheel revolution number, \( (N_g)_{max} \), is related to the allowance wheel speed \( (V_g)_{cr} \) or the maximum value, \( (D\cdot N)_{max} \), obtained from the product of wheel spindle diameter, \( D \), and spindle revolution number, \( N \), which equals to wheel revolution number, \( N_g \). Namely the \( (N_g)_{max} \) is calculated by \( C_g/D_g \) or \( C/D \) where \( C_g \) or \( C \) is \( (V_g)_{cr}/\pi \) or \( (D\cdot N)_{max} \), respectively.

From the consideration mentioned above, two methods are thought for making suitably the removal rate larger. Those are to increase the \( f_p \) and \( N_g \). Both methods are related to the wheel diameter. The increase of \( f_p \) under the same surface roughness must be accompanied with raising the wheel diameter to the 2nd power. Therefore the wheel diameter must be increased steeply as the \( f_p \) becomes large. The wheel diameter, however, is limited on manufacturing of wheel, grinder size and so on.

On the other hand, the increase of \( (N_g)_{max} \) under the same limitation needs to decrease proportionally the wheel diameter. The high speed spindle in which the spindle revolution number is over twenty times more than ordinal spindle can increase relatively easy the \( (N_g)_{max} \) though the wheel diameter is small.

From the point of view, the ultra-smoothness vertical grinding method shown in FIGURE 2 is devised. There are two reasons for the decision to the vertical grinding method. One is that the high speed spindle of small diameter is difficult to apply to the horizontal grinding method. Another is that in the vertical grinding method, the \( f_p \) can be made larger than the horizontal grinding method because the geometrical surface roughness in the vertical grinding method becomes so smaller than the horizontal grinding method.

FIGURE 3 shows the effect of the inclination of wheel axis on the surface roughness. In the vertical grinding method, the geometrical surface roughness of parallel direction \( (H_p)_{h'_{n}} \) is expressed for the \( (H_p)_{h_{n}} \) in the horizontal grinding method as follows:

\[
(H_p)_{h'_{n}} = (H_p)_{h_{n}} \times \cos \theta
\]

where \( \theta \) is inclination angle. From the equation (3), the smaller the \( \theta \) becomes, the smaller the \( (H_p)_{h'_{n}} \) becomes. To execute grinding at the \( \theta = 0 \) as shown in FIGURE 4, however, is considered
difficult from the point of the effect of grinding fluid supply and the occurrence of loading.
FIGURE 5 shows the comparison of removal rate obtained using horizontal surface grinder with using vertical surface grinder in the same geometrical surface roughness. In the calculation, the setting geometrical surface roughness, $H_{\text{max}}$, is 4nm. The wheel speed is the same of $V_g=50$ m/s. The wheel diameters used are $D_g=100$ mm in the horizontal grinding method and $D_g=14$ mm in the vertical grinding method, respectively. The inclination angle of wheel in the vertical grinding method is 3 degrees. From the figure, the removal rate in the vertical grinding method is found over 10 times larger than the horizontal grinding method.

EXPERIMENTS
FIGURE 6 shows the vertical grinder manufactured newly on trial. The main specifications of the grinder are listed in TABLE 1. The grinder is constructed with the mechanism of 4 axes. The grinder equips with the air spindle and X-Y table holding the workpiece whose movement accuracies are 62 nm. Wheel spindle is possible to be inclined with small angle from vertical direction. The vertical movement accuracy is 62nm.

The experiments are done with the new vertical grinder. The experimental conditions are listed in TABLE 2. The grain size and concentration of wheel used is #140 and 50, respectively. The workpiece and grinding fluid used are cemented carbide and soluble type. Normal feed per a wheel revolution ranges from 10 micro-
nm/rev to 100 micro-meters/rev. The workpiece surface and its surface roughness are observed with Nomarski microscope and SEM, and measured with a surface interferometer (WYKO:TOPO-3D).

RESULTS AND DISCUSSIONS
FIGURE 7 shows the cemented carbide surfaces ground at $f_{\text{gn}}=10$ micro-meters/rev and $f_{\text{gn}}=100$ micro-meters/rev using the new grinder. At the $f_{\text{gn}}=10$ micro-meters/rev, there are no cracks and grinding grooves on the surface. At the $f_{\text{gn}}=100$ micro-meters/rev, on the other hand, lots of cracks and grinding grooves are observed. The reason is considered why the $f_{\text{gn}}$ exceeds the wear width of active grain. It is clear from the result that in the vertical grinding method as well
as the horizontal grinding method, the $f_{Gn}$ can be increased in the range of only small value.

FIGURE 8 shows the comparison of the surface roughness formed by the vertical grinding method and the horizontal grinding method. The grinding conditions in horizontal grinding method is the same as that used in the vertical grinding method shown in Fig.7 except the $D_g=100$ mm. In both methods, the 3D surface roughness is about 40 nm ($R_s$) or 4 nm ($R_a$). It is referred that the surface smoothness in the ultra-smoothness vertical grinding method can be formed to almost the same level as the surface smoothness in the horizontal grinding method.

FIGURE 9 shows the surface roughness of the cemented carbide as shown in FIGURE 7(b). The 3D surface roughness is about 207 nm ($R_z$), or 15 nm ($R_a$). Compared with the surface roughness in FIGURE 8(a), Its roughness is found so large.

SUMMARY
The main conclusions obtained are as follows:
1. The ultra-smoothness vertical grinder which is designed has a ten times higher removal rate than horizontal grinder is manufactured successfully on trial.
2. The vertical grinder equips with high revolution spindle. For ultra-smoothness grinding, the small diameter wheel is used under high revolution.
3. Cemented carbide surface ground at $f_{Gn} = 10$ micro-meters/rev using vertical grinder attains about 32 nm ($R_z$), 5 nm ($R_a$).
4. The critical normal feed per a wheel revolution ($f_{Gn}$) exists for obtaining ultra-smoothness surface.

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REFERENCES