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FUNDAMENTAL STUDY ON CROSS AXIS GRINDING METHOD

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ABSTRACT

In this study, it is experimentally investigated that the surface generation process in the cross axis grinding method with small diameter grinding wheel. In this grinding method, workpiece surface speed and sum of both wheel working surface speed and wheel feed rate crossed each other. Therefore, it is the largest characteristic that the cross angle, which is defined as the angle between the workpiece surface speed and sum of the wheel speed and wheel feed rate, is able to set wide area with systematic parameter setting. Then, it is made clear that the surface roughness is getting smoother with decrease of the cross angle.

Keywords: grinding, cross angle, grinding velocity, surface roughness

1. INTRODUCTION

Plastic forming roll is widely used for production such as automobile door sash, because the plastic forming has advantages such as high productivity and low machining cost. Then, the roll is firstly generated external profile with lathe, and then heat treated for hardened, and finally polished to obtain smooth surface roughness. In order to product long life roll, it is necessary to make smooth and uniform finished surface. So, the roll is hand polished by expert in job shop. However, it will be certain that decrease of the experts in Japan in near future, so the mechanized and low cost finishing method for the roll polishing is desired in factories.

Therefore, in this study, the machining ability of the cross axis grinding method with the small diameter grinding wheel is experimentally investigated, in order to mechanize the surface finishing process of the roll for plastic machining.

2. CHARACTERISTIC AND EXPERIMENTAL METHOD

Figure 1 shows the experimental apparatus of the cross axis grinding. From the figure, the rotation axis of both the workpiece and the grinding wheel is geometrically cross angled. In this case, the workpiece surface speed and sum of both the wheel working surface speed and the wheel feed rate are crossed each other at the grinding point. Therefore, the relation between the wheel surface speed and the workpiece surface speed in this method is similar to the cross grinding method which is applied to the ultra-precision grinding for optical elements production [1]. Then, the cross angle θ is define as the angle between the workpiece surface speed V_w and synthesized grinding speed V at the grinding point.

In the cross axis grinding method, there are some characteristics mentioned below.

1) Because the drive motor and/or the bearings are hardly interfere with the workpiece, so the degree of freedom for the finishing tool design will be higher.
2) It is expected that the surface roughness is improved speedy, because the abrasive grain obliquely interfere the residual grooves which is generated by lathe previously.
3) It is expected that the surface roughness improvement carries on like the controlled force grinding mechanism, due to its low stiffness of the tool.
4) It is able to set the cross angle wide area with systematic machining parameter setting.

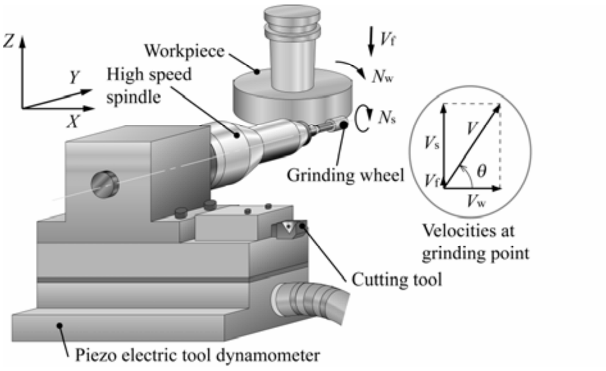

Figure 1. Experimental apparatus.

Furthermore, there is a characteristic in interference depth change of the individual abrasive grain, in an interference region between the grinding wheel and the workpiece. In a forward side of the interference region, maximum cutting depth of the grain increases from 0 to maximum value along the wheel width direction, so it is similar to the one in traverse grinding method. Therefore, it is possible that the smoother surface roughness could be obtained with coarser grain.

Experiment is carried on as mentioned below. The workpiece is settled to the vertical spindle of the machining center. The high speed rotating spindle with the small diameter CBN grinding wheel is fixed on the piezo electric tool dynamometer, mounted on the machining table. The rotating grinding wheel grinds the rotating workpiece surface with the setting depth of cut, and the wheel is fed along the workpiece width direction. If the cross angle θ=0 degree, only one round groove will be generated on the workpiece surface along the circumference. On the contrary, if θ=90 degree, only one flat line will be generated toward the workpiece width direction. So, the cross angle is limited in the range of $0<\theta<90$ degree, if the workpiece rotates in one direction. Furthermore, the grinding fluid is supplied during the grinding operation.

Main experimental conditions are as follows:

Grinding wheel: CBN180V (R_s=5mm), Workpiece: SK3 (HV=880, R_w=50mm), Grinding speed: 303m/min, Grinding wheel feed rate: V_f=7.0mm/min, Cross angle: θ=10-80 degree, Setting depth of cut: Δ=5m/rev. of workpiece, Grinding fluid feed rate: G_f=4.6L/min (Water soluble type, 1.25% concentration), Grinding system stiffness: k_{sys}=0.11N/μm ($1/k_{sys}=1/k_s+1/k_w$), Wheel support stiffness: k_s=0.12N/μm, Workpiece support stiffness: k_w=2.04N/μm.

3. ANALYSIS OF THE STOCK REMOVAL AND RESIDUAL AMOUNT

Figure 2 shows stock removal and residual stock in 1 pass grinding. Firstly, curve (1) in this figure is a standard surface, which is generated by sufficient spark-out grinding. Then, curve (2) is cross sectional workpiece profile, after 1pass grinding with certain setting depth of cut Δ. Before and after the 1pass grinding, two marker lines are generated by grinding at θ=0 degree, in order to specify the surface position in width direction. Furthermore, curve (3) shows the maximum depth in flat part, which is ground at θ=90 degree with stopped workpiece surface, in order to decide real setting depth of cut.

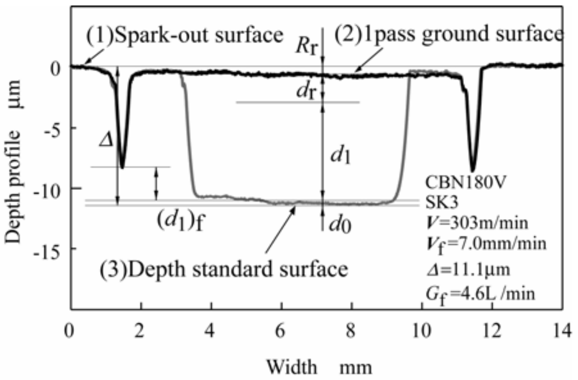

Figure 2. Stock removal and residual stock in 1 pass grinding.

It is made clear that the removal depth, which is calculated from the subtraction of the curves (1) and (2), is very small value. Then, difference between

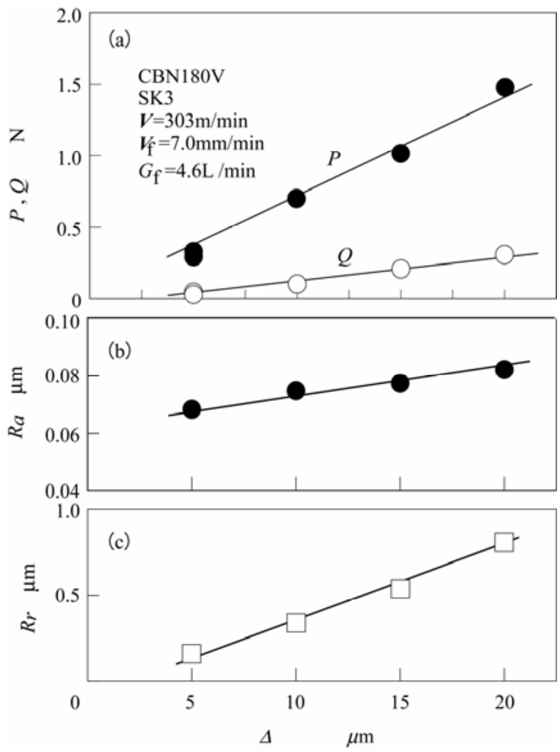

Figure 3. Influences of setting depth of cut to grinding force, surface roughness and removal amount.

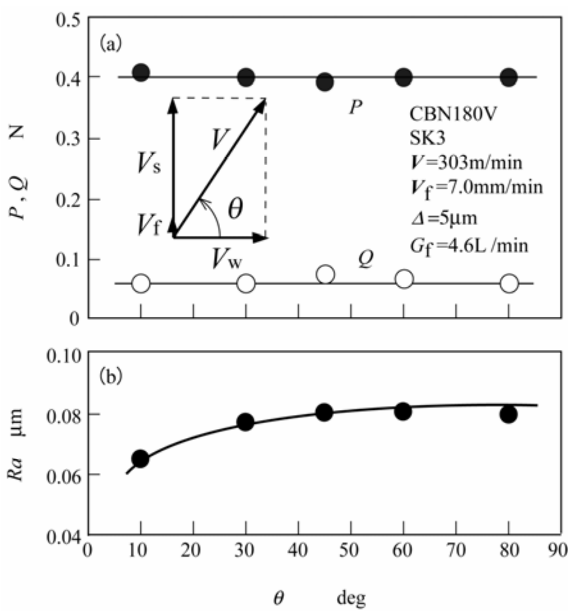

Figure 4. Influences of cross angle to grinding force, surface roughness.

the setting depth of cut and the removal depth, which is so called the residual amount. Therefore, it is necessary to decide the real setting depth of cut. The setting depth of cut is 11.1 μm, which is given by the sum of the depth of the curve (3) and final elastic residual amount $(d_1)_f$ (= (final normal grinding force)/k_{sy}). Wheel wear d_0 is 0.2μm, which is obtained by the difference between before and after grinding transcription curves of the rotating wheel working surface on acrylic resin plate. Furthermore, residual amount d_1 due to the elastic deformation in grinding is obtained by the division of the normal grinding force and the system stiffness. Residual stock dr due to the elastic and plastic deformation of the workpiece and grain is calculated from subtraction of the values mention above. From the above investigations, most of the value of setting depth of cut is absorbed into the residual amount d_1 due to the elastic deformation of the grinding system. Thereby, it is considered that the machining process carries on like the controlled force grinding mechanism in this method. Moreover, the grinding force keeps almost constant value in the grinding process, so the grinding condition is considered to be stable.

4. INFLUENCE OF GRINDING CONDITION TO GRIDING RESULTS

Figure 3 shows the influences of setting depth of cut to the normal grinding force P, tangential grinding force Q, surface roughness R_a and real material removal R_r, with only the setting depth of cut Δ is controlled except the grinding speed V, wheel feed speed V_f and the cross angle θ. From the figures, every grinding result is getting larger with increase of the setting depth of cut.

However, as the grinding force increases lineally with increase of the setting depth of cut, then the residual amount d_1 caused by the elastic deformation of the grinding system also becomes larger. So, it is expect that the increase rate of the substantial wheel depth of cut may be small. Therefore, the amount of the real stock removal is less than 1μm, though it increases lineally. Furthermore, the surface roughness also becomes slightly larger. So, the small amount of setting depth of cut leads to both little removal and smooth surface roughness.

Figure 4 shows the influences of the cross angle, which is systematically varied, to both the grinding force and the surface roughness, with the constant grinding speed V. From the figure, it is obvious that the normal grinding force P and tangential grinding force Q are almost constant. However, the surface roughness becomes smaller with decrease of the cross angle.

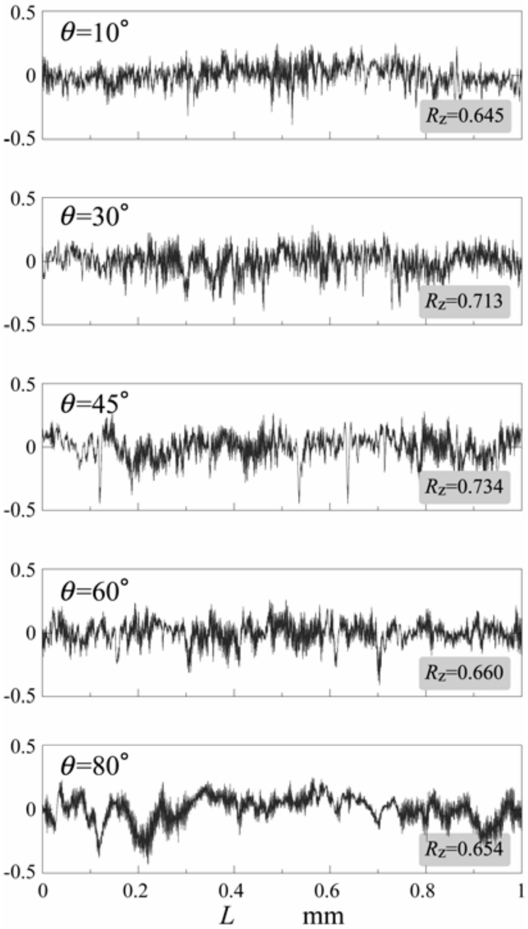

Figure 5. *Cross section profiles of ground surface with different cross angle.*

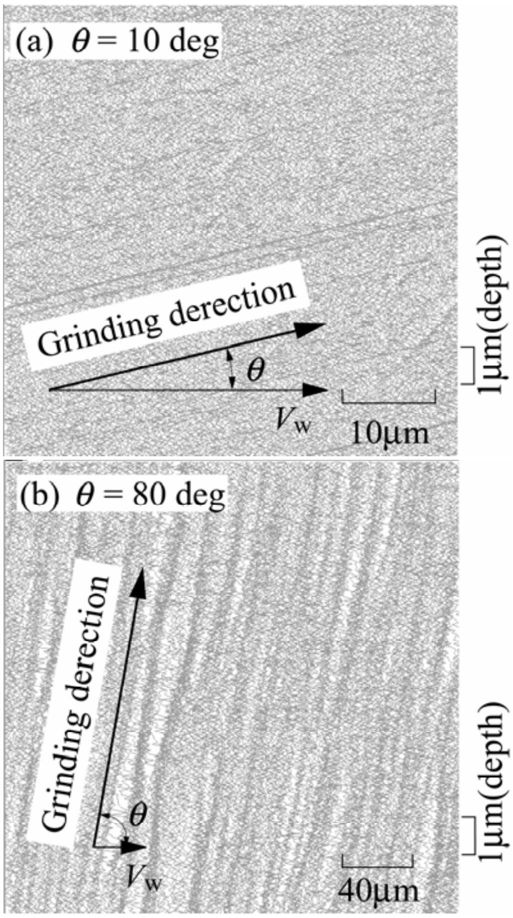

Figure 6. Three dimensional profiles of ground surface with different cross angle.

Figure 5 shows cross section of the ground surface in the workpiece width direction. From the figure, when the small cross angle, the profile consists from short cycle waves. However, with the increase of the cross angle, proportion of the long cycle wave becomes larger, and then the surface roughness becomes courser.

Figure 6 shows 3 dimensional profiles measured with contact probe type surface roughness tester. From the figure (b), in the case of large cross angle, large scale ground grooves lies along the grinding direction. However, from the figure (a), in the case of small cross angle, it is clear that each groove overlaps each other, and then smooth surface is generated.

When the cross angle is larger, the workpiece rotation is low speed and the wheel speed is higher, so the number of active grains are large. On the centrally, when the cross angle is smaller, the number of actual grains are little, but the grooves generated are piled up each other. Therefore, it is considered that the surface roughness becomes smoother in the small cross angle condition.

5. CONCLUSIONS

In this study, surface generation mechanism with the cross axis grinding method with small diameter wheel is investigated experimentally. It is made clear that the surface roughness along the workpiece width is influenced by the cross angle. If the cross angle is small, namely the grinding speed direction closes to the wheel speed direction, a groove generated by a grain becomes longer and piles up each other, and also a number of the grooves in a certain area of the workpiece becomes few, so the smooth surface roughness generated.

6. REFERENCES

[1] H. SUZUKI, Y. YAMAMOTO, T. MORIWAKI, T. OKINO, Y. HIJIKATA, J. ROBLEE, T. MIYASHITA: Development of Cross and Parallel Mode Grinding Machine for High NA Aspherical Mold, The Japan Society for Precision Engineering, 2006 Spring Anual Meeting , Chiba, Japan, 2006, p219-220.