A Study on the Surface Integrity of Grinding of Ceramics

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Abstract

Experimental investigations were carried out to find the characteristics of grinding of ceramics. Grinding mechanisms of ceramics were inspected through the microscopic examination. It has been found that the specific grinding energy of ceramics is relatively low as compared to that of steels. The specific grinding energy affects the surface roughness and the residual stress of ground surface. The experimental results indicate that the rougher surface finish and higher compressive residual stress are obtained at lower specific grinding energy. The surface roughness and the residual stress of the ground surface have significant effects on the strength of ground piece of ceramics.

Key Words : Ceramics, Grinding, Surface roughness, Residual stress, Bending strength, Specific grinding energy

1. Introduction

The use of ceramics has been greatly increased in the precision engineering. The machining of ceramics is usually performed by grinding process using diamond wheels. The grinding mechanism of ceramics is somewhat different from that of steels. The ceramics are ground by brittle fracture whereas the steels are ground by continuous shear in the contact zone between wheel and workpiece. For this reason, the grinding of ceramics causes surface flaws such as macro/micro cracks and chippings. These flaws affect the surface roughness and the strength of ceramics.[1,2,5,6]

Grinding process also creates residual stresses on the ground surface. Grinding -induced residual stresses cause detrimental effects on the strength and geometry of ground parts.[1,3,4,7] Therefore, it is very important to understand the effects of surface roughness and residual

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stress on the strength of ground ceramic parts.

In this investigation grinding experiments were carried out at various grinding conditions for major types of ceramics including Al_2O_3, SiC, Si_3N_4, and ZrO_2 to elucidate the effects of grinding parameters on the surface roughness and residual stress.

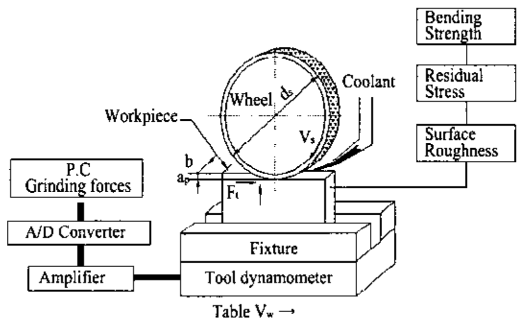
2. Experiments

In the experiments, the surface grindings for ceramic materials were carried out using the experimental system depicted in Fig. 1(a). The grinding machine used is horizontal type surface grinder(YGS-50A) with 1.5 kW spindle motor rotating at 3,440 rpm. The grinding wheels used on the experiments were resin bonded diamond wheels having N grade and 100 concentration. The diamond wheels were carefully dressed before every experiments with WA sticks at the dressing conditions described in table 1.

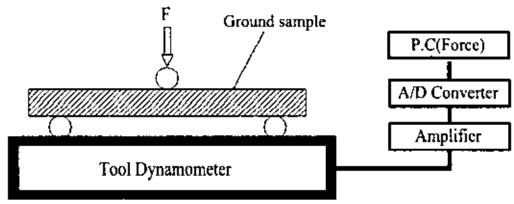
Table 1 Experimental conditions

Grinding machine	Horizontal type surface grinding machine Model: YGS-50A(1.5 kW, 3,440rpm)	
Grinding wheel	SDC100N100B, SDC200N100B, SDC400N100B(180D×31.75d×15w)	
Workpiece	Al_2O_3, SiC, Si_3N_4, ZrO_2	
Grinding conditions	Wheel speed(V_s): 32.4 m/s	
	Table speed(V_w): 0.4 - 12 m/min	
	Depth of cut(a_p): 5 μm - 150 μm	
	Grinding type: traverse & wet	
Grinding fluids	water miscible syntilo 25(50:1)	
Bending Test	80 mm/min	
XRD conditions	Speed : 0.01/3[deg/(sec/step)] 2θ-position : 116～127 slit : 1mm	
Dressing conditions	Dressing stick	WA100, 200, 400 stick(100L×21W)
	Grinding type	traverse & wet
	Depth of cut	20, 30 μm
	Table speed	6 m/min
	Cross feed	5 mm/pass

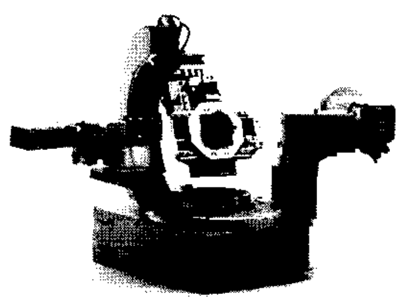
The tested workpieces are Al_2O_3, SiC, Si_3N_4, and ZrO_2. During grinding experiments the grinding forces were measured using piezo-electric type tool dynamometer(Kistler, 9257B) and the specific grinding energy is calculated. The ground surfaces were examined by SEM(Scanning Electron Microscope) and optical microscope. Surface roughness values were obtained by surface tracer(Mitutoyo, SV-600). Residual stress measurement was conducted on the X-ray diffractometer(Bruker-AXS series D5005, Fig. 1(b)). The



(a) Experimental set-up



(b) 3 point bending test on machining center



(c) X-ray diffractometer

Fig. 1 Experimental system

strength of the ground specimen is acquired by 3 point bending test using tool dynamometer on the machining center(Fig. 1(c)).

2. Results and Disscussion

2.1 Grinding mechanism of ceramics

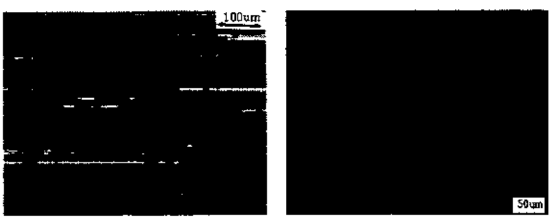
To investigate the grinding characteristics of ceramics, the grinding mechanism of the ceramic is compared with that of the steel.

Fig. 2 shows the micrographs of grinding debris of steel(STD11, HRc 60) and Al_2O_3 ceramic after grinding. The grinding debris of steel is continuous type but the grinding debris of ceramic is fractured type. Fig. 3 shows the photographs of the ground surface of steel and ceramic. It can be easily seen that the steel was removed by ductile plastic deformation and the ceramic was removed by brittle fracture.

From these observations, it can be concluded that the ceramic material is removed by brittle fracture whereas the steel is ground by plastic flow as schematically illustrated in Fig. 4.

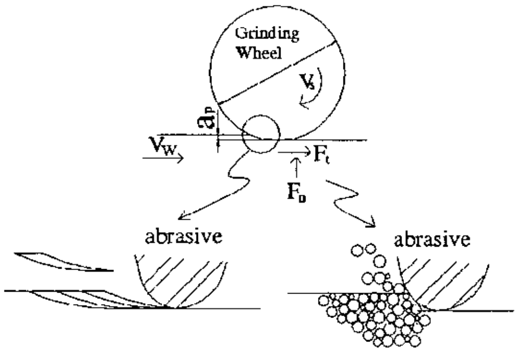
(a) steel (b) ceramic

Fig. 2 SEM micrographs of grinding debris of steel and ceramic



(a) steel (b) ceramic

Fig. 3 SEM micrographs of ground surfaces



(a) steel (b) ceramic

Fig. 4 Grinding mechanisms of steel and ceramic

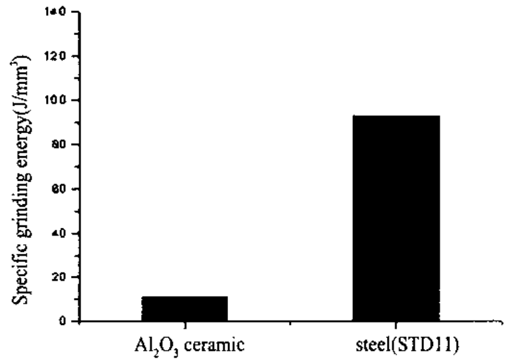


Fig. 5 Specific grinding energy for grinding Al_2O_3 ceramic and tool steel (a_p =5μm, v_w =6m/min)

The difference on the material removal mechanism can be also seen in the specific grinding energy measurement. The specific grinding energy of the Al_2O_3 ceramic is compared with that of steel(STD11, HRc 60) in Fig. 5. The specific grinding energy of ceramics is much lower than that of steel. These results indicate that the ceramic consumes much less energy than steel due to the brittle mode material removal.

2.2 Surface roughness at various grinding conditions

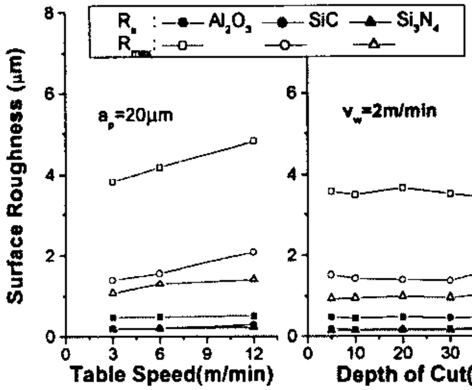


Fig. 6 Grinding conditions versus surface roughness of Al_2O_3, SiC, and Si_3N_4

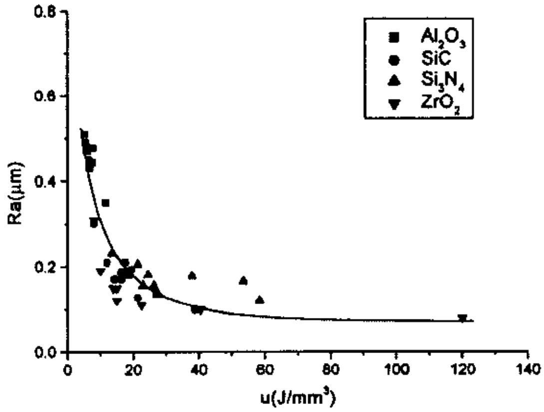


Fig. 8 Ra versus specific grinding energy

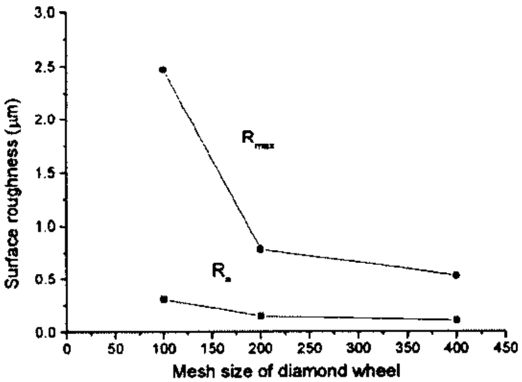


Fig. 7 Mesh size versus surface roughness for grinding of ZrO_2 ceramic

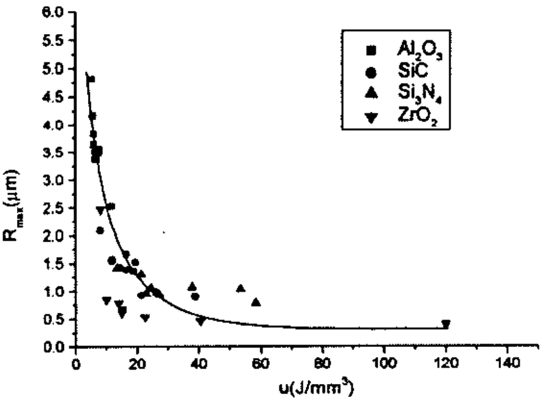


Fig. 9 Rmax versus specific grinding energy

The variation of the surface roughness with the grinding conditions is investigated. Fig. 6 shows the surface roughness for major structural ceramics including Al_2O_3, SiC, and Si_3N_4. Table speed is varied from 3 m/min to 12 m/min and depth of cut is varied from 5 μm to 40 μm. The surface roughness values are increased slowly as the table speed increased but almost same values of surface roughness were obtained at the range of depth of cut tested. The effect of wheel abrasive size on the surface roughness was tested using ZrO_2 ceramics and the results are presented in Fig. 7. A rapid decrease in surface roughness value was observed as the abrasive size decrease.

2.3 Specific grinding energy and surface roughness

The relationship between specific grinding energy and surface roughness was also investigated. Fig. 8 and 9 show the arithmetic average value of surface roughness(Ra) and the maximum value of surface roughness(Rmax) versus the specific grinding energy, respectively. Through the Fig. 8 and 9, it can be seen that the surface roughness is related with the specific grinding energy. The smoother surface is obtained at the higher specific grinding energy.

2.4 Residual stress in ceramic grinding

Because the magnitude of residual stress on the ground surface is one of the controlling factors affecting the strength of ground parts, the residual stress measurement was executed for the ZrO_2 ceramics.

Fig. 10 and 11 shows the residual stress values at various grinding conditions and for different wheels, respectively. The change in the magnitude of residual stress was very similar with the change in the surface roughness. In other words, compressive residual stress was increased slowly with the increase in table speed and not much change was observed with increase in depth of cut. The compressive residual stress, however, decreased rapidly with the decrease in the abrasive size of the diamond wheel.

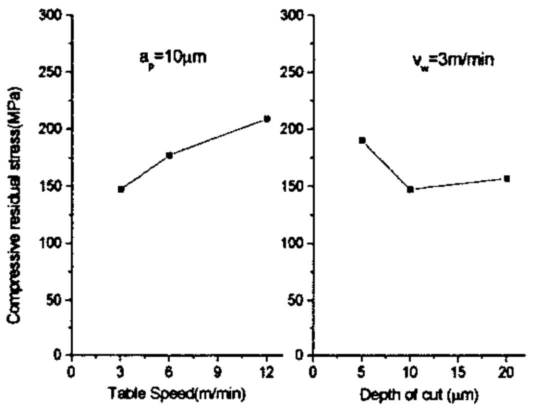


Fig. 10 Grinding conditions versus residual stress for ZrO_2 Ceramic

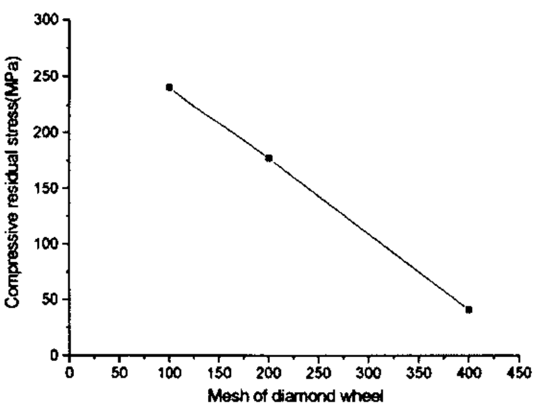


Fig. 11 Mesh size of diamond wheel versus residual stress for ZrO_2 Ceramic

2.5 Specific grinding energy and residual stress

Fig. 12 shows the relationship between specific grinding energy and residual stress. Compressive residual stress decreases exponentially with the increase in the specific grinding energy. This phenomenon can be explained by the temperature effect. The high grinding temperature which occurs at the grinding condition of high specific grinding energy acts to create the residual stress in tensile direction which means the reducing in the compressive residual stress.

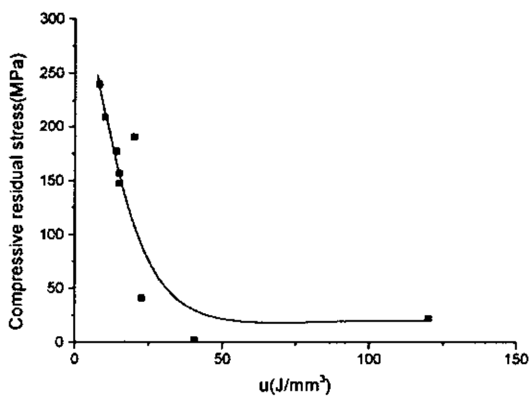


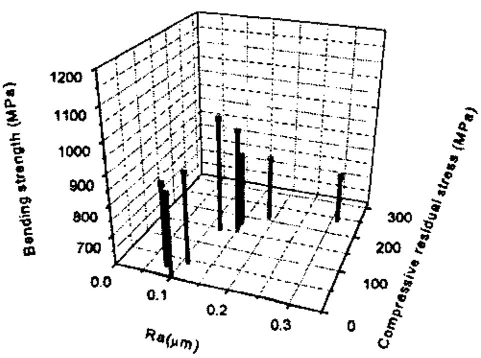
Fig. 12 Specific grinding energy and compressive residual stress

2.6 Bending strength of ground ceramics

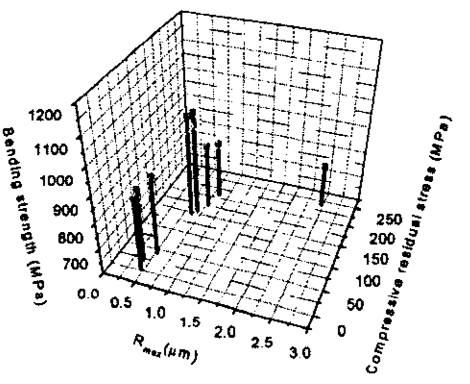
It has been shown earlier that the grinding actions result in wide range of surface roughness and residual stress. Obviously these changes on ground surfaces affect the strength of ground parts. 3 point bending tests were carried out to see the effects of the changes in the strength of ground ceramics and very interesting data were obtained.

Table 2 Bending strength, R_a, R_{max}, and residual stress

Ra	Rmax	Residual	Bending
0.31	2.47	240	764
0.15	0.78	177	845
0.12	0.61	147	983
0.19	0.84	209	816
0.10	0.51	190	946
0.15	0.67	157	943
0.11	0.53	41	903
0.08	0.40	22	877
0.10	0.46	2	875



(a) Bending strength, Ra, and residual stress



(b) Bending strength, Rmax, and residual stress

Fig. 13 Bending strength of ground ZrO_2 ceramics

The experimental results presented in Fig. 13 show that the bending strength is maximum at certain values of surface roughness and residual stress. For the case of ZrO_2 ceramics tested, the bending strength was maximum at the surface roughness value of 0.12 μm R_a and the compressive residual stress value of 147 MPa. This phenomenon can be explained as follow. The bending strength of smoother surface was lower because the magnitude of compressive residual stress is small and the bending strength of rougher surface was also lower because the deeper valleys at rougher surface act as notches. R_{max} has the same tendency with R_a.

3. Conclusions

The following conclusions were obtained from the experimental investigations for the grinding of ceramics;

(1) The specific grinding energy of ceramics is much lower than that of steels because ceramics are removed by brittle fracture.
(2) The surface roughness of ceramics is related with the specific grinding energy. The grinding conditions of high specific grinding energy result in smoother surface.
(3) Diamond mesh size of grinding wheel is one of the controlling factors that affects the surface roughness and residual stress.
(4) Residual stress is related with specific grinding energy. Compressive residual stress is reduced as the specific grinding energy is increased.
(5) The bending strength is maximum at certain values of surface roughness and residual stress. The bending strength of smoother surface was lower because the magnitude of compressive residual stress is small and the bending strength of rougher surface was also lower because the deeper valleys at rougher surface act as notches.

Acknowledgement

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