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A Study on the Grindability of Ceramics by Wet Lapping

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Abstract
The recording industry is one of the dominant users of new ceramics such as alumina, silicon carbide and zirconia. An experimental method are conducted into the lapping of alumina, silicon carbide and zirconia using diamond powder abrasive to study the effect of process parameters such as grain size, lapping pressure, lapping velocity and surface roughness. As a result, the size of the abrasive is proportional to the specific stock removal and surface roughness. The lapping volume increasing with the lapping velocity that is permitted within the limits of the critical lapping velocity(v_c = 250 *m/min*).
Also, wear of the lapping abrasive and surface topography have a retro effect on the contact conditions, the stress collective, and matching of the active partners(shape, size).

Keywords: Supper precision, Ceramics, Diamond powder, Lapping, Surface topography

INTRODUCTION

Businesses have recently focused their attention on developing electrical and electronic materials with chemical safety, light weight, and high hardness by using materials with electrical-electronic functions and heat-resistant mechanical structure use, such as ceramics, ferrite, and silicon. In terms of production, these materials are hard to cut and difficult to be processed using general machine tools, and therefore rely on superfine processing such as grinding or lapping processing.
However, lapping requires development of processing methods that improve surface quality, such as surface roughness and accuracy of shape, for the processed materials. Research trends regarding this include the study on machinability of fine ceramics based on fuzzy logic[1]. There is a need to consider the machinability of lapping, such as surface roughness or wear volume in accordance with the size and lapping speed of abrasive grains that go in processed materials and surface plate (lapping plate). Notably, there is a need to conduct studies which indicate that, in the system for removing machining, such as lapping, the size of the abradant or the surface shape of the processed materials may have a large influence depending on the background condition of contacting sides[2], or those that suggest that, since a surface plate is a rigid body with low elasticity in lapping processing test, separation or fraction of particles may occur due to gaps between processed materials and surface plate[3]. Theoretical or experimental studies on gaps and friction of surface quality are required as well.
As a means to improve surface and shape accuracy, this study paid a close attention on wear volume, lapping speed, and amount of offset, etc. of average abrasive grain according to size or on superfine processing by analyzing processing surface or discharged chips through grinding experiments.

EXPERIMENT DEVICE AND METHODS

SYD-630D was used for the experiment to process the material with certain depth(Δ) using a two-side lapping machine with central gear installed in lapping plates on the top and bottom. Also, the bending strength of silicon carbide ceramic was tested using a bending tester (3-point bending test: universal tester).
Also, as shown in Figure 1, the diameters of surface plates on the top and bottom of the lapping machine are all Φ630*mm*, and sintered diamond powder (#400) is inserted in plug form (Φ25*mm*) in a lapping plate with Sn background. The wet surface plate in Figure 2 is a tool which automatically transports slurry mixed with solution and abradant (diamond particle).

Figure 1: The lapping machine

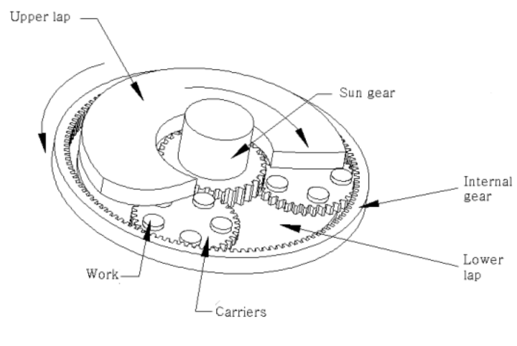

Figure 2: Double-sided lapping machine

In order to process precise products, pressurization was applied on the lapping machine (number of spindle rotation: 45~65*rpm*), with pressure to be applied (200~250*N*). Detailed grinding conditions are shown in Table 1.

Table 1: Experimental conditions

Apparatus	Double-side lapping machine	
Workpiece	Various ceramics	
Abrasive grain	Diamond #200~4000	
Lapping time	1~90 [*min*]	
Lap	Material	Metal oxide, Sintered diamond
	Slurry	Carbide abrasive, Water
Speed	20~300 [*m/min*]	
Pressure	1~100 [*kPa*]	

Processed ceramics products which were used for the experiment were Alumina(Al_2O_3), Silicon Carbide(SiC), and Zirconia (ZrO_2), and silicon carbide (SiC) ceramic went through bending test (3-point bending tester). Degree of hardness and physical values are shown in Table 2. Also, grinding resistance was measured using a tool dynamometer (for milling grinding) with octagonal elastic ring.

Table 2: Properties of workpiece material

Workpiece Material	Vickers hardness (GPa)	Fracture toughness ($MNm^{-3/2}$)	Young's modulus (GPa)
Alumina (Al_2O_3)	20.5	4.1	308
Silicon Carbide(SiC)	21.3	4.4	401
Titanium Carbide(TiC)	8	6	181
Zirconia (ZrO_2)	12.6	8	205
Zirconia (ZrO_2)	13	9	210

RESULTS AND DISCUSSION

Grinding and polishing of the kind of simulation

1) Characteristics of ceramics and metal

Figure 4 shows the characteristics of ceramics and metal by showing deformation of each material when pressing on the two materials using a steel ball. Pressing metal with a steel ball causes plastic deformation right under the metal, but no brittle failure occurs. However, in ceramic material, Hertzian crack, which is a ring-shaped fracture, occurs around the contacting part[6]. Fracture occurs on the surface and progresses to a significant level. This is thought to present a method for processing ceramic, which has brittleness. Therefore, it can be a good method for machinability study to examine the bending strength of processing groove that occurs on the surface.

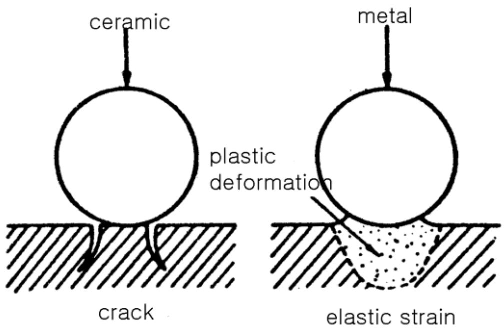

Figure 3: Comparison of steel ball on ceramic and metal surfaces

2) Surface roughness of SiC ceramic according to bending strength

The surface of silicon carbide (SiC) consisting of particle (below multiple) was finely grinded. Then, a rough crack was made using a SiC abradant with different size in order to study the consequent bending strength.

As shown in Figure 4, the bending strength is approximately 70kg/mm^2 until surface roughness reaches 0.5μm. While it is approximately 65kg/mm^2 at roughness of 1μm, the strength sharply drops afterwards. Therefore, if the surface roughness processed with an abradant was greater than 1μm, it was observed that the bending strength drops sharply. If the surface is very precise, the bending strength of silicon carbide (SiC) ceramic increases, but there is a certain range for this, so it is thought that superfine processing will not result in an increase with high degree.

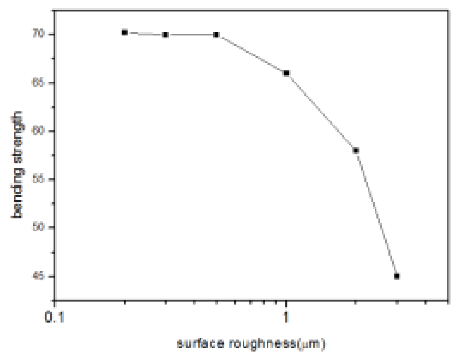

Figure 4: The relation of surface roughness and bending strength at SiC ceramic.

3) Surface roughness according to applied load and time

Figure 5 and Figure 6 show the phenomenon where surface roughness decreases if applying load increases in the initial stage. This is thought to be caused by reduction of lapping resistance with increased lapping speed.

Figure 7 shows changes in surface roughness according to processing time. Surface roughness slightly increases by processing time. However, if lapping is continued, irregular tear-type chips occur more frequently than flow-type chips due to pore filling or pore blockage of whetstone.

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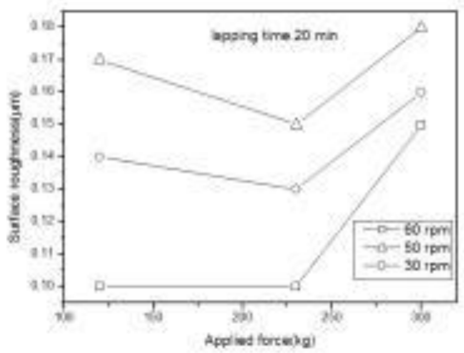


Figure 5: Surface roughness after 20 minutes lapping at various applied force

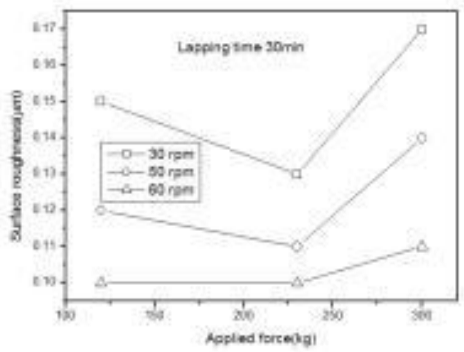


Figure 6: Surface roughness after 30 minutes lapping at various applied force.

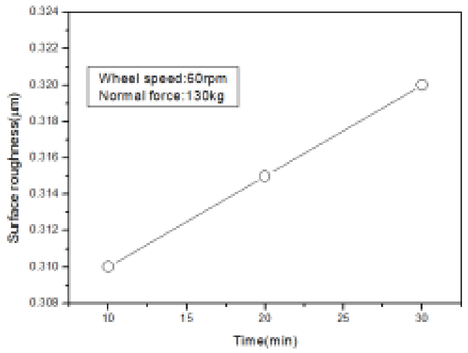


Figure 7: Relationship between surface roughness and lapping time.

Lapping conditions and characteristics

The most important grinding factors in lapping processing are lapping speed and pressure. In general condition, first setting the lapping speed (10*m/min*) and pressure (230*kg*) and then applying the amount of stock removal to be proportional to lapping speed lead to superfine processing.

While lapping characteristics are different according to processed materials and lapping materials, the amount of stock removal was maintained consistently according to lapping speed(*m/min*), pressure (*Pa*), and time in order to perform superfine lapping with high accuracy. Then, the ratio of the amount of stock removal to pressure is indicated with proportional constant ($\mu m^{-1}/Pa$), ratio of stock removal) and is called processing efficiency.

Figure 8 and Figure 9 show surface roughness and ratio of stock removal according to average size(mesh) of abradant when lapping processed material(Al_2O_3). Just like the mechanical characteristics of grinding particle, surface roughness increases in near proportion as the average size of the abradant increases.

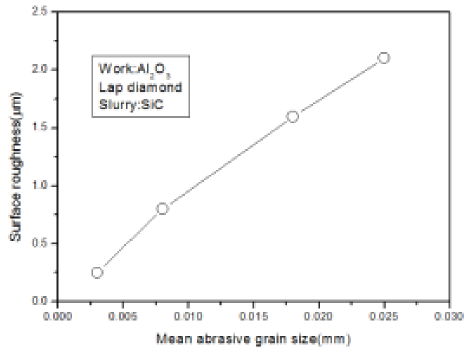


Figure 8: Relationship among mean abrasive grain size or surface roughness

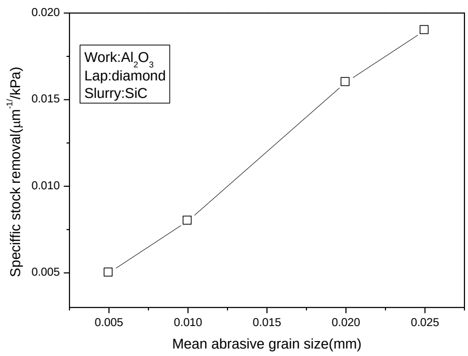


Figure 9: Relationship among Mean abrasive grain size or Specific stock removal.

Lapping power

1) Speed of table and abrasion simulation

Figure 10 and Figure 11 show values obtained by wet-grinding SiC ceramics. Each indicates changes in wear volume according to abrasion velocity and distance (offset).

When a structure is lapped with the same rotation direction and number of rotation as well as consistent rotating angular velocity (ω), there is a certain critical value of lapping volume depending on grinding velocity. Therefore, wear volume increases with near proportion up to a certain abrasion velocity (critical velocity), but saturation occurs if it exceeds the critical velocity (υ_c).

If the velocity increases again, the lapping volume increases, but tends to decrease after a certain critical velocity (approximately 100*mm/min*).

If pressure is consistent, grinding volume changes according to grinding time or distance. As shown in Figure 11, lapping volume increases according to offset (distance) and then tends to decreases again after passing the critical point with a certain value (approximately 80*mm*).

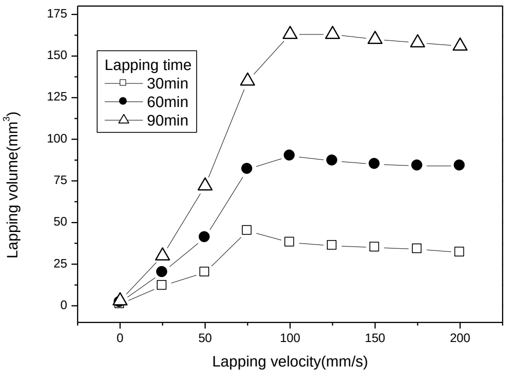


Figure 10: Relation between lapping velocity and lapping volume.

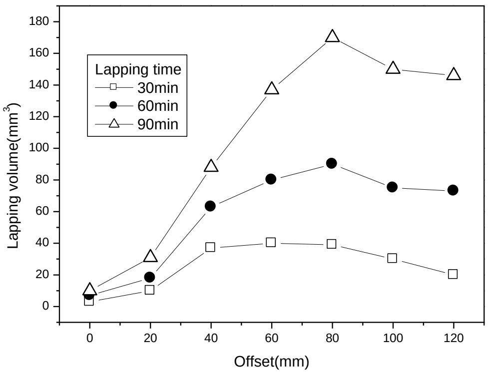


Figure 11: Relation between lapping offset and lapping volume

As explained above, lapping volume in the initial offset range is nearly proportional to lapping distance.

Organization of structure

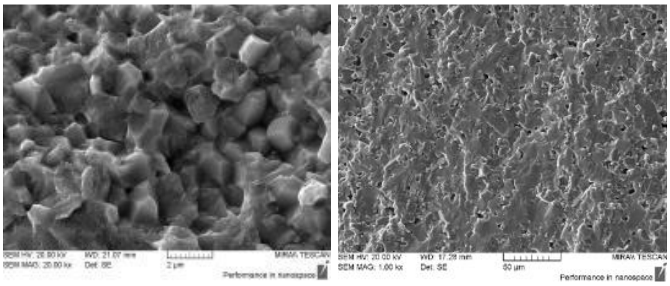
1) Observation of ceramics surface

Following are the results of analyzing the ceramics that have gone through superfine processing (Al_2O_3, SiC, ZrO_2) using SEM imaging and EDS.

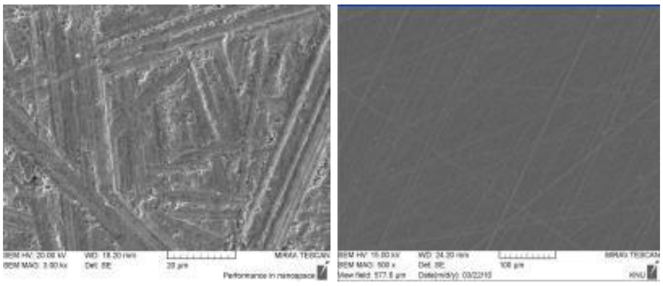
The pits, which always appear on the lapping surfaces are due to the intrinsic porosity of the sample by the SEM analysis. (a) Interference optical images of tribochemically lapping surfaces in different solutions. In addition, some particles are destroyed. (b) Smooth surface, the pits are intrinsic holes; Some grains are lapped faster than others crystallographic orientations. and The smooth polished is. (c) In distilled water, surface looks like long straight marks (b), and also has waviness. (d) Tiny scratches exist due to grains felling out.

SEM image of Alumina ceramics in Figure 12 (a) shows very rough aluminum powder (grey, over approximately 50*m*) and fine alumina (white). Also, while the surface of lapped alumina ceramics is damaged a little, slight scratch is shown in Zirconia in (c). Also, analyzing the processed materials using EDS shows that low amount of C or O ingredients are detected in all ceramics specimens along with main ingredients.

Meanwhile, for silicon carbide (SiC) sintered for 30 minutes at 1550°C, the size of silicon carbide particles (white) is 1~15*m*, and silicon(grey) is filled in the gaps between SiC particles.



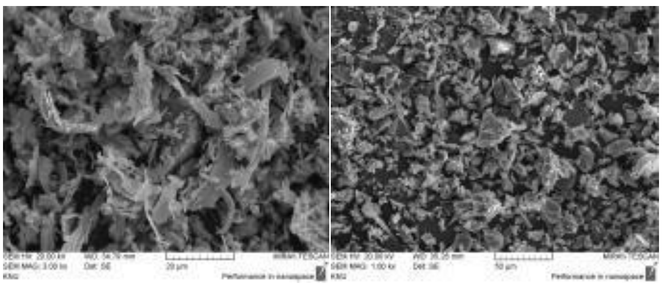
(a) ZrO_2 (b) Al_2O_3



(c) TiC (d) ZrO

Figure 12: SEM image of Alumina(Al_2O_3) ceramics(a) and Zirconia (ZrO_2)

Figure 13 shows SEM image of chips that were obtained by lapping ceramics with particles of 25*m*, 12*m*, and 6*m*. While flow-type chips are observed, most of them are sheared or fractured chips or chips in fragments. Processing TiC ceramics using a grinding whetstone below 12*m* produces chips that are close to continuous flow-type. Failures surface with brittle is observed in finished surfaces for Al_2O_3 ceramics as well, but the overall shape is the same.



TiC chip(grain size:12*mm*) Al_2O_3 chip(grain size:12*mm*)

Figure 13: Chip formations according to materials (TiC and Al_2O_3)

CONCLUSION

When lapping new ceramics [Alumina(Al_2O_3), Silicon Carbide(SiC), Zirconia(ZrO_2)], machinability by wet-lapping with a diamond (or silicon carbide) abradant was studied in order to obtain the following conclusions.

1) If surface roughness is above 1μm in silicon carbide (SiC) ceramic, the bending strength was shown to

decrease sharply.

2) When lapping Al_2O_3 ceramics, surface roughness and the rate of stock removal increases in proportion to the size of diamond particle.
3) When considering wear volume according to grinding velocity or distance, there are critical velocity (approximately 100*mm/min*) or critical offset amount (approximately 80), where the volume increase or decrease around the critical values.
4) Observing the lapped surface shows that plastic deformation occurs at TiC, ZrO ceramics than ZrO_2, Al_2O_3. While there is a slight mark of scratch, the surface is clean.

ACKOWLEDGMENTS

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