

# Influence of the brittle behavior of work materials on polishing characteristics

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**Abstract.** Diamond electrodeposited wire tools are frequently used to cut thin wafers from hard and brittle materials. However, microcracks sometimes appear during the slicing process. The appearance of microcracks adversely affects slicing efficiency and slicing accuracy. In this study, we examine the influence of brittle behavior on the polishing characteristics such as polishing depth and tool wear. This is the first step toward investigating the influence of the brittle behavior of work materials on slicing characteristics. Ceramics such as alumina, silicon carbide, and zirconia are used as work materials. Even with the same degree of hardness, we found that the polishing depth values were greater for materials exhibiting brittle behavior. In the polishing of high-hardness materials, abrasive grains were badly damaged during the initial stages of polishing. Damage to the abrasive paper was less in wet polishing as compared with dry polishing. Moreover, wet polishing had a greater polishing depth than dry polishing. The polishing characteristics of the brittle materials were similar to the grooving characteristics produced using wire tools; however, both these characteristics depend on the brittle behavior of the work materials. Therefore, by performing simple polishing tests, estimating the state of grooving or slicing using wire tools is possible.

## 1. Introduction

Multi-wire sawing is an excellent slicing method for electronic or optical parts made from hard and brittle materials, such as silicon ingots, magnetic materials, ceramics, and sapphires. In recent years, multi-wire saws using diamond electrodeposited wire tools have gained acceptance as a mainstream slicing method for large-diameter ingots or high-hardness materials [1, 2]. However, microcracks may occur during the slicing of hard and brittle materials. Such microcracks negatively influence the slicing efficiency and the slicing accuracy. In addition, they prevent wafer thinning. Therefore, it is important to clarify the relation between the brittle behavior of the work materials and the processing characteristics.

In our previous studies, we have investigated multi-wire sawing to achieve precise and very efficient slicing of hard and brittle materials [3, 4]. This study aims to examine the influence of the brittle behavior of the work materials on slicing characteristics such as the generation mechanism of the sliced surface and wear characteristics of the wire tool. In this report, we examine the influence of brittle behavior on the polishing characteristics. This is the first step toward investigating the influence



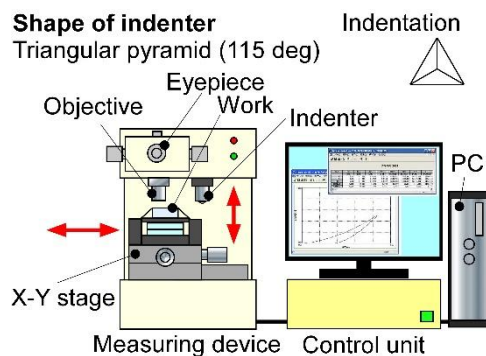
of the brittle behavior of the work materials on the slicing characteristics. Therefore, we performed loading-unloading tests and polishing experiments for various ceramics.

## 2. Experimental procedure

Figure 1 shows the schematic of a nanoindenter used in this study and summarizes the conditions for the loading–unloading tests (see table 1). Loading–unloading tests were performed using a triangular pyramid diamond indenter. The measuring force was 500 mN, and the loading rate was 0.7 mN/s. The holding time was 10 s.

Figure 2 shows the schematic of the reciprocating abrasion tester used for the experiment. Table 2 summarizes the conditions for the polishing experiments and materials used. The distance of the reciprocating movement was 100 mm, and the polishing time was a maximum of 30 min. The table speed (i.e., the reciprocating speed) was 1212 mm/min. The polishing load applied to the work materials was 26.7 N. Ceramic plates such as alumina ( $\text{Al}_2\text{O}_3$ ), silicon carbide (SiC), and zirconia ( $\text{ZrO}_2$ ) were used as work materials. The cross-sections of the work materials were rectangles with dimensions of 10 mm  $\times$  3 mm. In the previous study, we had clarified that  $\text{Al}_2\text{O}_3$  and  $\text{ZrO}_2$ , which we used as work materials, have almost the same hardness. SiC has a greater hardness than both  $\text{Al}_2\text{O}_3$  and  $\text{ZrO}_2$  [5]. In wet polishing, a glycol-based water-soluble coolant was used as the working fluid. The wet polishing experiments were conducted in a liquid medium.

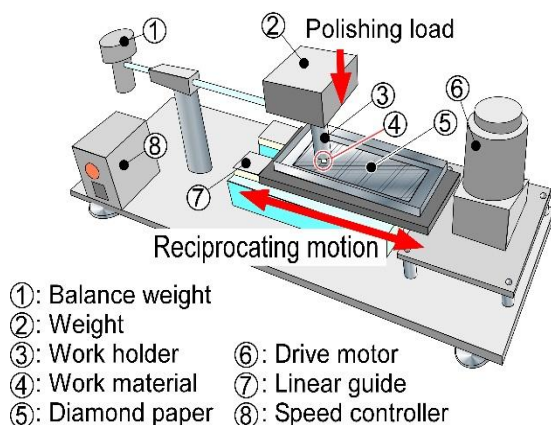
A scanning electron microscope (SEM) image of the unused diamond abrasive paper is shown in figure 3. The abrasive paper was made up of diamond grains fixed on a copper plate via nickel plating. The particle size of the diamond grains was approximately 30  $\mu\text{m}$ .



**Figure 1.** Schematic of the nanoindenter.

**Table 1.** Experimental conditions for loading-unloading test.

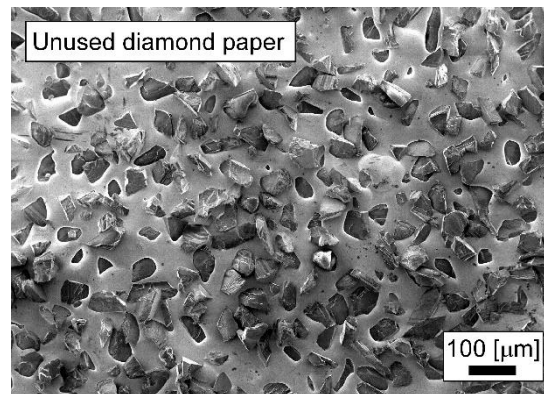
Indenter	
Shape	Triangular pyramid
Ridgeline angle	115 [°]
Indenter	500 [mN]
Indenter	0.7 [mN/s]
Indenter	10 [s]



**Figure 2.** Schematic of the abrasion experimental setup.

**Table 2.** Conditions for polishing experiments and materials used.

Abrasive paper	
Abrasives	Diamond grain
Particle size	30 [ $\mu\text{m}$ ]
Base material	Nickel-plated copper plate
Work material	$\text{Al}_2\text{O}_3$ , SiC, $\text{ZrO}_2$
Cross section	Rectangle (3 $\times$ 10 [ $\text{mm}^2$ ])
Polishing speed	1212 [mm/min]
Polishing load	26.7 [N]
Polishing time	30 [min]
Moving distance	100 [mm]

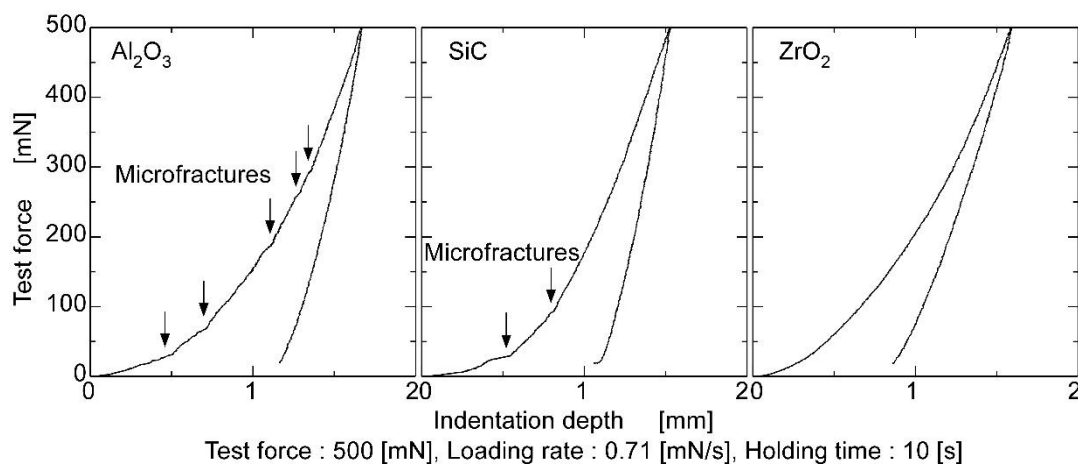


**Figure 3.** SEM image of the unused diamond abrasive paper

### 3. Experimental results and discussion

#### 3.1. Results of loading-unloading test

Results of the loading-unloading test are shown in figure 4. For  $\text{Al}_2\text{O}_3$  and SiC, we confirmed the presence of multiple microfractures that preceded the indenter. However, no microfractures were observed in the loading-unloading test performed for  $\text{ZrO}_2$ . This result proved that  $\text{Al}_2\text{O}_3$  and SiC demonstrate more brittle behavior than  $\text{ZrO}_2$ .



**Figure 4.** Results of loading-unloading test.

#### 3.2. Influence on polishing depth

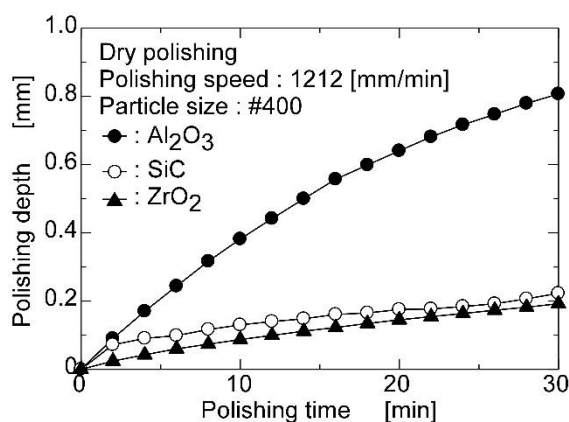
Figure 5 shows the relation between the polishing time and the polishing depth. This is the result of dry polishing. The polishing depth of each material increases with the passage of polishing time. The polishing depth of  $\text{Al}_2\text{O}_3$  is greater than  $\text{ZrO}_2$  of similar hardness. The brittle behavior of  $\text{Al}_2\text{O}_3$  is remarkable compared with other work materials, which is one of the reasons for the increase of the polishing depth (see figure 4). In addition, SiC with high hardness has a slightly greater polishing depth than  $\text{ZrO}_2$ . SiC has high hardness, and  $\text{ZrO}_2$  has high toughness; therefore, we did not observe any remarkable increase in the polishing depth accompanying the polishing time.

Figure 6 shows the relation between the polishing time and the polishing depth in wet polishing. The polishing depth of wet polishing is much greater than that of dry polishing. As compared with dry polishing, the polishing depth of each material increased linearly with the passage of polishing time (see figure 5). This is because the loading (or clogging) of the diamond abrasive paper was suppressed. In particular, remarkable effects are obtained with  $\text{Al}_2\text{O}_3$  and  $\text{ZrO}_2$ . Diamond grains of the abrasive

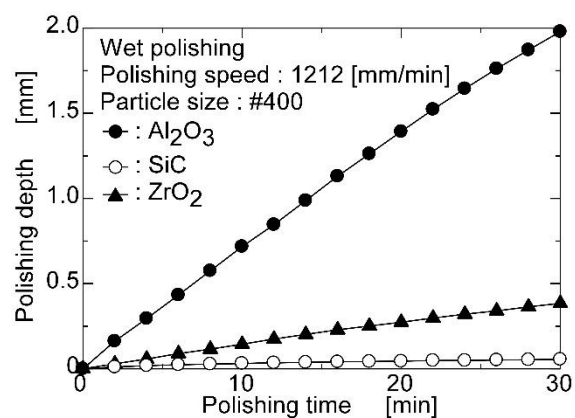
papers were badly damaged during SiC polishing because SiC has high hardness. Therefore, the effect of suppressing the loading is considered to be small.

Figure 7 shows the polishing depth per unit time in dry polishing, and figure 8 shows the results of wet polishing. In wet polishing, the polishing depth per unit time is much greater than that of dry polishing. The polishing depth of the work materials decreased with the passage of polishing time. However, in wet polishing of  $\text{Al}_2\text{O}_3$  and  $\text{ZrO}_2$ , it was possible to maintain the polishing depth per unit time. We obtained these results because the loading (clogging) of the diamond abrasive paper was suppressed. Although SiC has high hardness, it showed brittle behavior similar to  $\text{Al}_2\text{O}_3$ ; therefore, the polishing depth at the initial stage of polishing was high. However, the polishing depth per unit time of SiC greatly decreased with the lapse of polishing time. This is because polishing of SiC having high hardness caused severe damage to the abrasive paper at the initial stages of polishing.

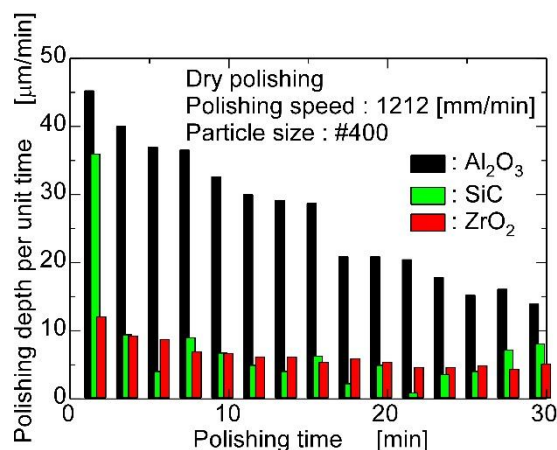
These results obtained are similar to the trends observed in groove processing using a diamond electrodeposited wire tool [5, 6].



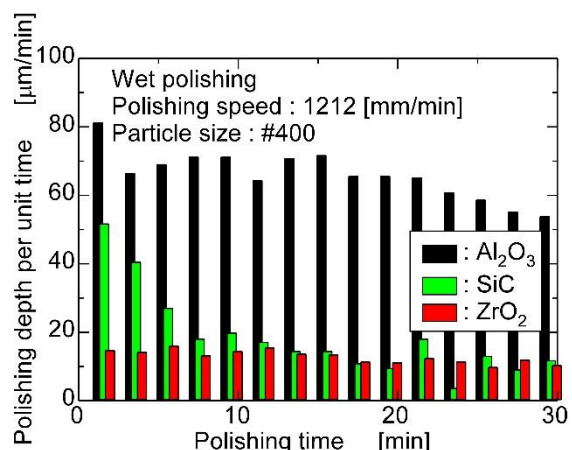
**Figure 5.** Relation between polishing time and polishing depth in dry polishing.



**Figure 6.** Relation between polishing time and polishing depth in wet polishing.



**Figure 7.** Relation between polishing time and polishing depth per unit time in dry polishing.



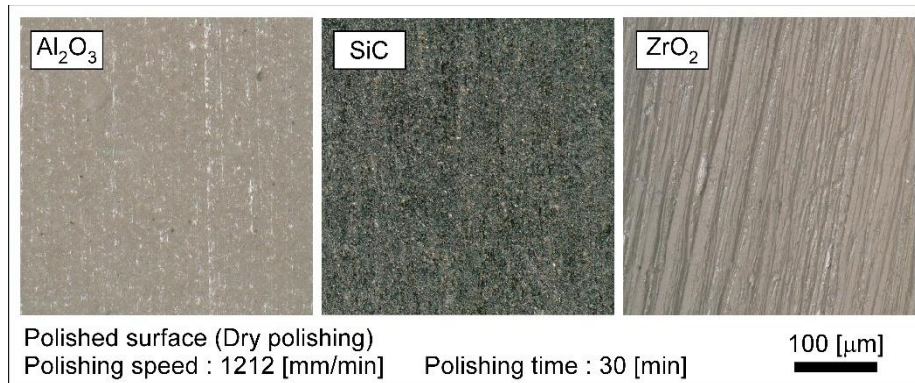
**Figure 8.** Relation between polishing time and polishing depth per unit time in wet polishing.

### 3.3. Influence on polished surface

Figure 9 shows images of polished surfaces for dry polishing. The polishing time was 30 min. The properties of the polished surfaces of  $\text{Al}_2\text{O}_3$  and SiC are quite similar. However, scratch marks due to the diamond abrasive grains of the abrasive paper were clearly visible on the polished surface of  $\text{ZrO}_2$ . This is probably because  $\text{ZrO}_2$  has greater toughness than  $\text{Al}_2\text{O}_3$  and SiC. The wet polished surface



was almost the same as the dry polished surface, and scratch marks were clearly visible only on the polished surface of  $\text{ZrO}_2$ .

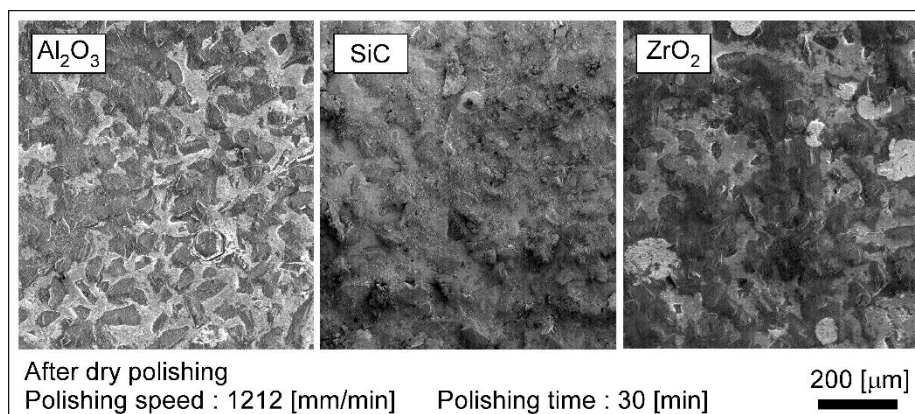


**Figure 9.** Examples of results of load-unloading test.

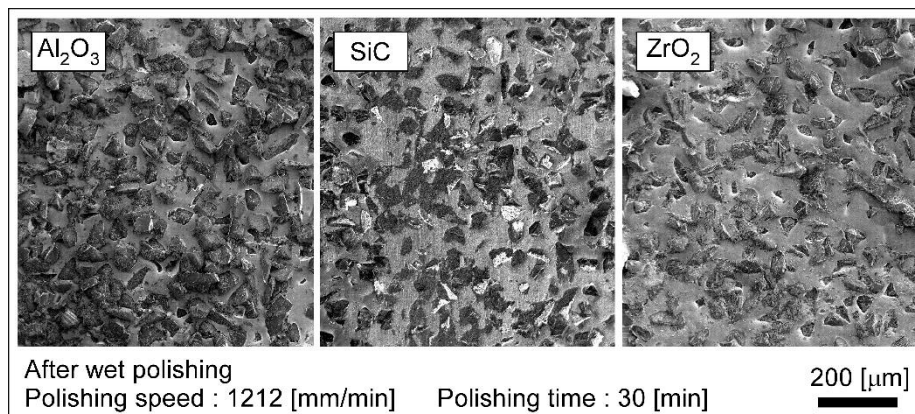
### 3.4. Influence on diamond abrasive paper after polishing

Figure 10 shows the images of the diamond abrasive papers after dry polishing for 30 min. All the diamond abrasive papers were severely damaged in the dry polishing experiments. In addition, loading occurred in all the abrasive papers. In the polishing of  $\text{Al}_2\text{O}_3$ , the diamond abrasive grains were worn out; however, the diamond abrasive grains could be clearly observed on the abrasive paper. In the polishing of  $\text{ZrO}_2$ , diamond abrasive grains could be observed despite severe loading. However, it was impossible to clearly confirm the presence of diamond abrasive grains on the abrasive paper after the polishing of SiC.

Figure 11 shows the images of the diamond abrasive papers after wet polishing for 30 min. As with dry polishing, all of these abrasive papers were damaged. Particularly, after the polishing of SiC, the diamond abrasive grains in the abrasive paper were worn out and flattened. However, the presence of diamond abrasive grains could be confirmed on all abrasive papers. In wet polishing, if the lubrication is improved and loading is suppressed, damage to the abrasive paper will be reduced.



**Figure 10.** Diamond abrasive paper after dry polishing for 30 min.



**Figure 11.** Diamond abrasive paper after wet polishing for 30 min.

These results are similar to the trends observed in our previous experiments wherein the wear characteristics of a wire tool were observed during grooving using a diamond electrodeposited wire tool [5, 6]. In other words, it became clear that it is possible to estimate the machining state when using a wire tool by performing simple polishing tests.

#### 4. Conclusions

We experimentally investigated the influence of the brittle behavior of work materials on polishing characteristics. The main conclusions obtained from this study are as follows. The hardness and brittle behavior of the work materials affect the polishing characteristics. Even with materials having the same degree of hardness, the polishing depth of materials that exhibit brittle behavior will be greater. In the polishing of high-hardness materials, the abrasive grains were badly damaged in the early stages of polishing. Damage to the abrasive paper was less in wet polishing as compared to dry polishing, and the polishing depth in wet polishing was greater than dry polishing. The results of this study confirm the results obtained by grooving using a diamond electrodeposited wire tool. Therefore, it is possible to estimate the state of grooving or slicing using fine wire tools by performing simple polishing tests.

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