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Tribological Properties of Sintered Diamonds with WC-Co Matrix

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Sintered diamond/(WC-Co) composites were prepared by spark plasma sintering technique. Tribological properties were measured at temperatures from RT to 500°C in sliding tests with alumina ball. They show coefficient of friction of 0.1 and below at RT and wear of the diamond composites is hardly detected. Effects of diamond grit size, diamond content and test temperature on the coefficient of friction and the wear are discussed. The wear scars were analyzed.

Key words : Sintered diamond, Tribology, Wear, Coefficient of friction

I. Introduction

Diamond is widely used in cutting tools and wear parts because of its superior hardness and wear resistance. However the toughness is not necessarily strong enough. On the other hand, WC-Co cemented carbides have high toughness but the wear resistance is much lower than diamond. Polycrystalline diamond composed of diamond layer and WC-Co substrate is a tool material making the best advantages of diamond and cemented carbides. However, it is very expensive as it is made by ultrahigh pressure technology. Recently a less expensive sintered diamond with WC-Co matrix produced in the MPa pressure range has been developed using HIP, SPS, etc.[1]

In the present study, the above diamond composites were sintered by spark plasma sintering (SPS) and tribological properties such as wear and coefficient of friction were measured from room temperature (RT) to high temperature in air

II. Experimental

1. Specimens

Diamond, WC and Co powders shown in Table 1 were mixed in an mortar using methanol. The mixed powders and WC-Co powder for the substrate were put one upon the other in a graphite mold and sintered by SPS in a similar way as in a the previous report.[2] The SPS was carried out in a vacuum of about 10 Pa, at a pressure of 65 MPa and at 1180°C for 5 min. Sintered discs with 20 mm diameter and 5 mm thick were ground and cut with diamond wheels into a rectangular prism of about 16× 10×5 mm. Thickness of the diamond layer and the substrate is about 0.5 and 4.5 mm, respectively.

2. Friction and wear tests

With a reciprocal motion high temperature friction/wear tester[3] friction and wear properties from RT to 400°C were measured. A 10 mm alumina ball was used as the mating material. The load was 19.6 N and the friction speed was 1.2 m/min.

III. Results and Discussion

1. Effects of diamond grain size on the friction and wear properties

Table 2 shows specific wear rate of diamond layer and alumina ball and coefficient of friction at stable friction range measured for 30 vol% diamond layers with different diamond size.

Specific wear rate of the 3~6 μm grit diamond layer is about half of mating alumina ball. However, for the diamond layers with over 4~8 μm grit diamond, no clear wear is detected with a stylus profile meter. Specific wear rate of alumina ball and coefficient of friction decreases as the diamond size increases and they both show remarkable decrease with 6~12 μm grit.

The surface of ground diamond layer is not necessarily completely smooth because some diamond particels are pulled out during grinding. A finer particle is more easily pulled out as the holding strength by binder is lower- comparing to a coarser particle. As a result, the wear of alumina ball and the coeficient of friction are larger in a finer diamond layer. Large wear of 3~6 μm grit diamond layer is considered to be caused by pulling out of diamond during friction.

2. Effects of diamond content on the friction and wear properties

In the case of 50 vol% 20~30 μm grit diamond layer, specific wear rate of alumina ball is 6.8×10^{-7} mm^3/Nm, coefficient of friction is 0.07 and wear of diamond layer is not detected even after 180 min (216 m) friction. These results indicate that the tribological properties are im-

Table 1. Raw Materials Used in the Diamond Layer

Diamond grit size, μm	A: 3~6, B: 4~8, C: 6~12, D: 20~30
Diamond content, vol%	A,B,C=30, D=30, 50
Binder phase	WC-1 wt%Co
WC, Co particle size	approx. 1 μm

Table 2. Friction Test Results of 30 Vol% Diamond Layers (friction time: 60 min, friction distance 72 m)

Diamond grit size μm	Sp. wear rate, Diamond layer	10^{-7} mm^3/Nm Alumina ball	Coefficient of friction
A: 3~6	45.4	104	0.65
B: 4~8	nil	55.9	0.55
C: 6~12	nil	7.1	0.09
D: 20~30	nil	9.0	0.09

proved by increasing diamond content.

3. Change in coefficient of friction with friction time

Fig. 1 shows change in coefficient of friction of 50 vol% 20~30 μm diamond layer during the friction test at RT. Coefficient of friction in the beginning of friction shows a higher value of 0.2 to 0.4, but it is rapidly decreased to 0.1 level at about 10 min. Thereafter, it is relatively stable mostly below 0.1, i.e. 0.08 at 60 min, 0.06 (minimum) at 160 min and 0.08 at 180 min.

In addition to above mentioned pulling out of diamond, hard to grind diamond particles may slightly stick out from the binder surface. This surface roughness is considered to be the reason of higher coefficient of friction in the beginning of friction. The roughness is filled up with friction time by transfer of mating material to the friction surface of diamond layer, and coefficient of friction is decreased.

4. Dependence of coefficient of friction on friction temperauture

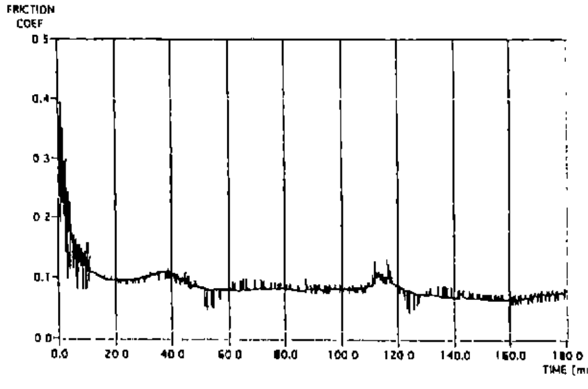
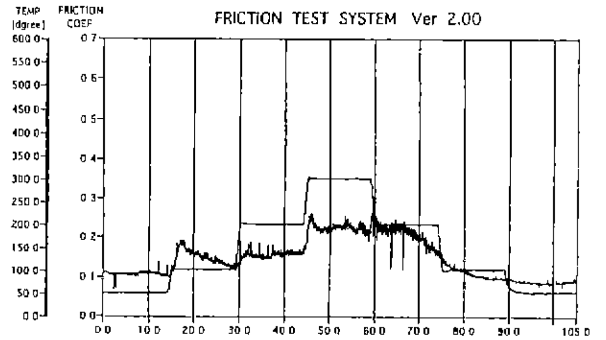


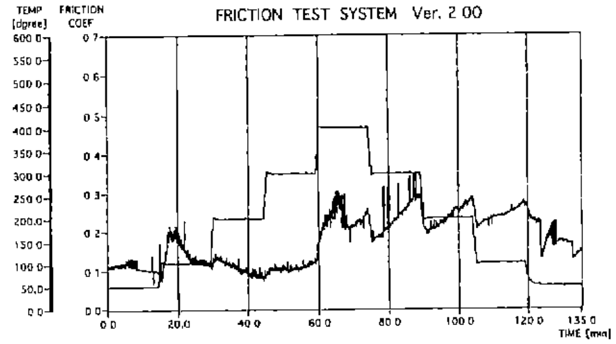
Fig. 1. Change in coefficient of friction of diamond layer with friction time.

Fig. 2(a), (b) and (c) show examples of change in coefficient of friction between RT(43~50°C) and 300°C, 400°C and 500°C, respectively. The temperature was kept at RT, 100°C, 200°C, 300°C, 400°C and 500°C respectively in both heating and cooling processes. Heating and cooling between each step was done in 1 min, and the temperature was kept for 14 min at each step. To avoid unstable coefficient of friction, preliminary 10 min friction was applied at RT before the measurement.

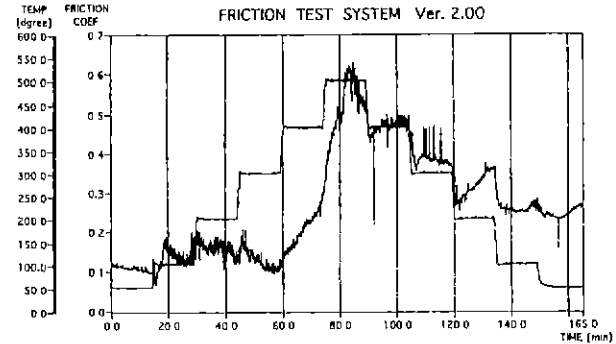
As shown in Fig. 2 coefficient of friction is about 0.1 in the beginning of friction (RT), but it is increased as the temperature rises. The maximum coefficient of friction at 300°C (a), 400°C (b) and 500°C (c) is 0.22, 0.28 and 0.62 respectively. In the case of maximum heating temperature of 300°C (a), coefficient of friction shows nearly the same value in heating and cooling process. While in



(a) RT - 300°C



(b) RT - 400°C



(c) RT - 500°C

Fig. 2. Effect of friction temperature on coefficient of friction of diamond layer.

the case of 400°C (b) and 500°C (c), coefficient of friction in the cooling process is higher than that in the heating process. High coefficient of friction at high temperature and in the cooling process may be due to slight oxidation of WC matrix.

5. *Observation and analysis of the friction surface*

Figure 3 shows optical microstructure of the wear scars of diamond layer and alumina ball after 60 min friction at 43°C and 100°C. On the surface of diamond layer, wear scars like Fig. 3(a) and (c) are observed, but no clear wear is detected with a stylus profilometer. The wear of alumina ball at 100°C is larger that at 43°C as shown in Fig. 3(b) and (d) with a specific wear rate of 2.0×10^{-5}mm^3/Nm and 2.8×10^{-6}mm^3/Nm, respectively.

Images of SE, BSE and W and Al characteristic X-ray on the above wear scars of diamond layer are shown in Fig. 4 and Fig. 5. In both Figs, it is confirmed by characteristic X-ray images of (c) and (d) that black areas in SE images of (a) and BSE images of (b) are diamond, while white and light gray areas are W rich phases and dark gay areas are Al rich phase. The results indicate that transfer film from the ball is formed on the rough friction of diamond layer during friction and the surface becomes smoother compared to before friction.

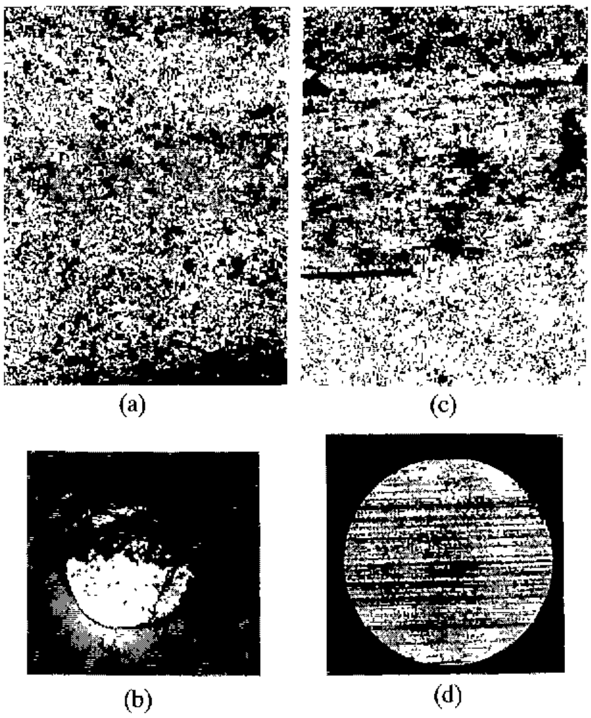

(a) (c)
(b) (d)

Fig. 3. Optical microstructure of wear scars. (a) diamond layer (43°C), (b) alumia ball (43°C), (c) diamond layer (100°C) and (d) alumina ball (100°C).

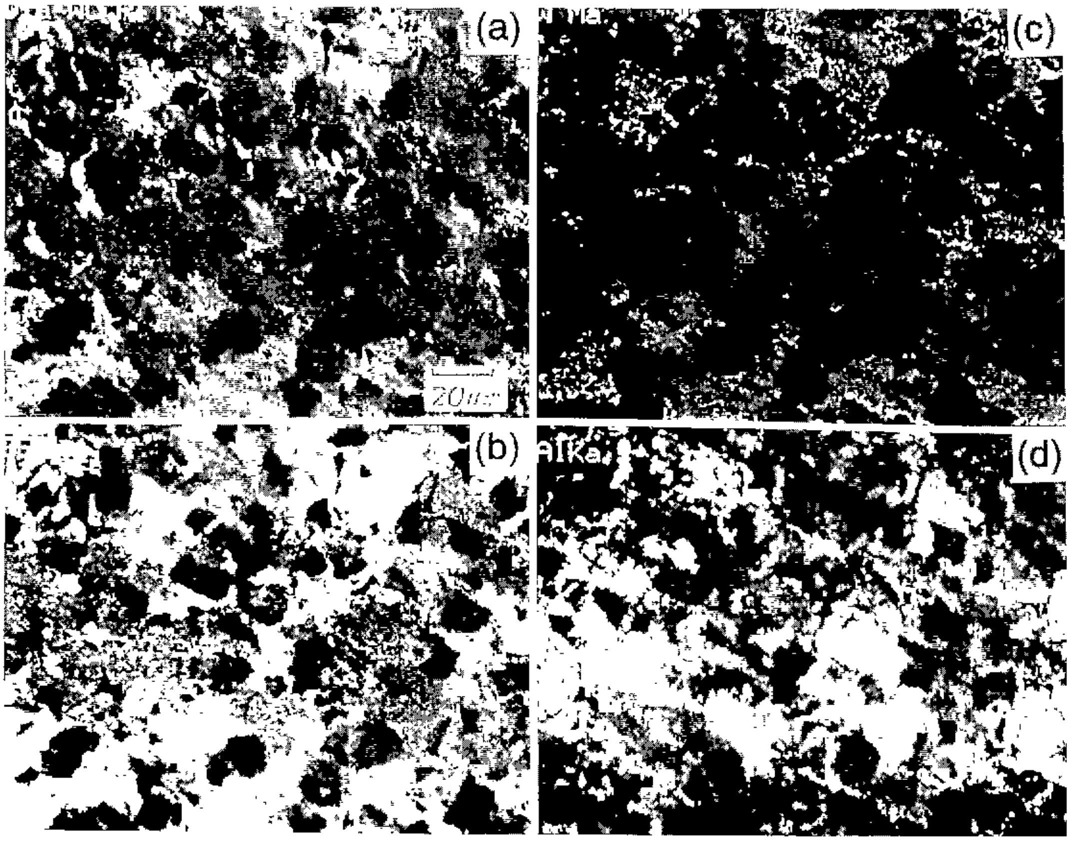


Fig. 4. EPMA images of wear scar of diamond layer (43°C). (a) SE image, (b) BSE image, (c) Characteristic X-ray image of W and (d) Characteristic image of Al.

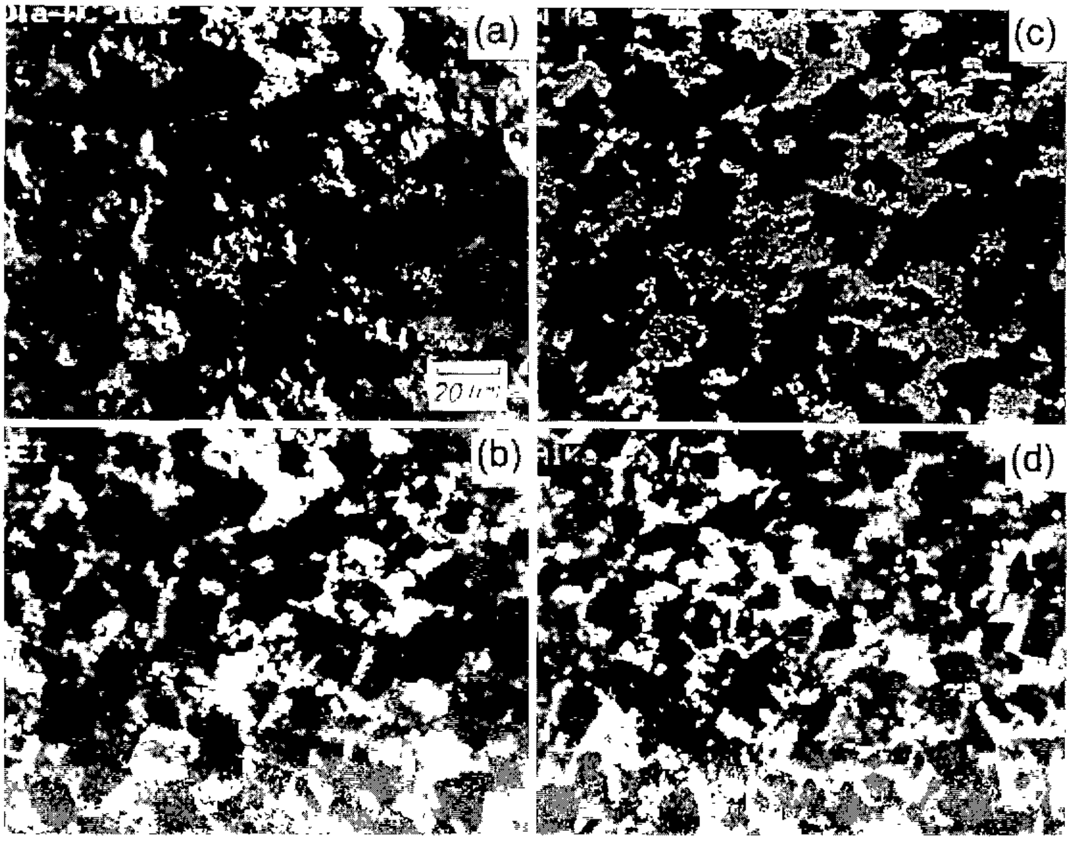


Fig. 5. EMPA images of wear scar of diamond layer (100°C). (a) SE image, (b) BSE image, (c) Characterlistic X-ray image of W and (d) Characteristi X-ray image of Al.

IV. Summary

1. Wear resistance and coefficient if friction of sintered diamond with cemented carbide binder are improved as the particle size of diamond increases.
2. In sliding test between sintered diamond and alumina, coefficient of friction at room temperature shows a maximum of about 0.1 at the beginning of friction, but it is below 0.1 in the stable friction stage.
3. Sliding tests at elevated temperatures show that the coefficient of friction and the wear of the alumina ball are increased at temperatures up to 400°C.

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