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Mechanical Properties of CVD Diamond

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This paper focuses the strength and wear resistance of CVD diamond films. The strength of free-standing CVD diamond films synthesized by microwave plasma CVD, DC plasma CVD, RF plasma CVD and arc discharge plasma jet CVD has been measured by three-point bending test The wear resistance of CVD diamond films has been evaluated by the pin-on-disk type testing. Diamond films coated on the base of sintered tungsten carbide pin by hot filament CVD have been rubbed with a sintered diamond disk in muddy water. Volume removed wear of CVD diamond has been compared with stellite, WC alloy and bearing steel.

Key words : CVD diamond, Film, Mechanical properties, Bending strength, Wear resistance

I. Introduction

CVD diamond is hopeful about its applications to mechanical and wear-resistant components as it is believed to have excellent strength and wear resistance. However, CVD diamond has not been widely used in industry against our expectations. This is mainly because of our lack of knowledge about the mechanical properties of CVD diamonds caused by the difficulties of making test pieces using conventional diamond processing techniques and by the slow progress of synthesis techniques for high quality diamond that is available. In this study, the bending strength of free-standing CVD diamond films and the wear resistance of CVD diamond films are discussed.

II. Bending Strength

The strength of free-standing CVD diamond films are measured by three-point bending test. Diamond films have been synthesized by microwave plasma CVD.[1] DC plasma CVD,[2] RF plasma CVD[3] and arc discharge plasma jet CVD.[4] These free-standing CVD diamond films are mechanically polished using metal bonded diamond wheel, after that cut by YAG laser irradiation[5] at desired dimensions. The shape of test piece is rectangular cross sectional plate and its dimensions were determined at above 10 mm long, about 3 mm width and 0.2~0.6 mm thick. Sintered diamonds that have the same shape as CVD diamond test pieces were selected as a reference material.

Figure 1 shows the three point bending test set-up. A special support device for CVD diamond test piece has been prepared for the bending test. Each test piece is mounted on tungsten carbide rods put on the lower support, and a load point rod and the upper support are set on the test piece. Concentrated load is applied in the middle of the test piece. Concentrated load is applied in the middle of the test piece by pushing the upper support through a load cell and tensile stress occurs at lower surface of the test piece. Test pieces are loaded over the span L of 8 mm at the crosshead speed of 0.1 mm/min. The load was measured with the load cell once a second until the fracture of the test piece.

In order to use plate theory to analyze the data of load and deflection it is necessary that load-deflection relationship is linear. Figure 2 shows the relationship between applied load and deflection under the load point of the test pieces synthesized by arc discharge plasma

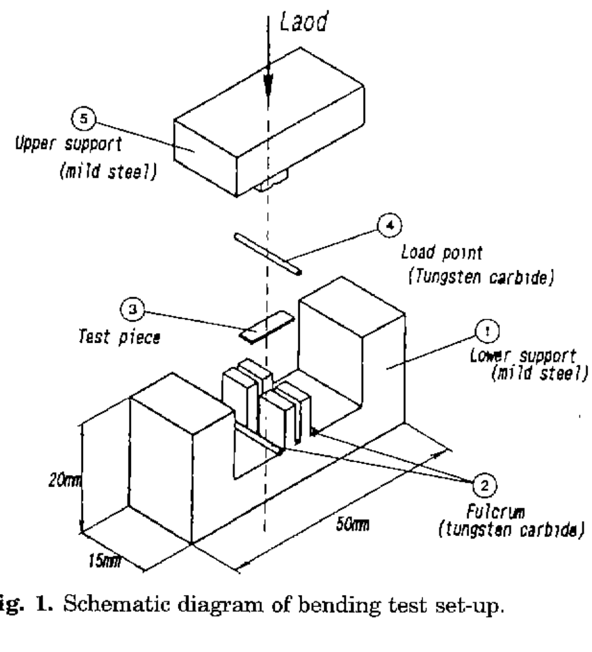

Fig. 1. Schematic diagram of bending test set-up.

jet CVD RF plasma CVD and DC plasma CVD. The linearity shown in this figure suggests that plate theory is applicable. Thus the three point bending strength σ_{3b} can be obtained using the following formula.

$$\sigma_{3b}=3PL\ 2wt^{2}$$

where P is load, w and t are width and thickness of test preces respectively.

Results of bending test are summarzied in Table 1. Most ruptures have been occurred under the load point. Distribution of calculated bending strength is shown in Fig. 3.

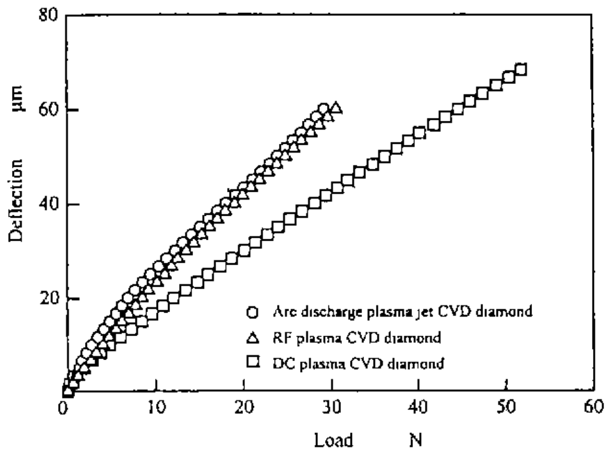

Fig. 2. Load versus deflection of CVD diamonds.

Table 1. Results of Bending Test

Synthesis method	Thickness (μm)	Tensile side	Rupture load (N)
DC plasma CVD	344-470	Bothsides (polished)	25.5-63.4
Microwave plasma CVD	227-259	Nucleation side (unpolished)	17.1-18.4
RF plasma CVD	377-565	Nucleation side (unpolished)	25.0-63.4
Arc discharge plasma jet CVD	227-440	Necleation side (polished)	4.2-29.3
Sintered diamond (25 μm)	471-512	(polished)	71.6-89.2

The bending strength of dc plasma CVD diamond is comparable to that of sintered diamond which consists of grains at average particle size of 25 μm. Wide distribution is shown in the strength of microwave plasma CVD diamond. RF plasma CVD diamond and arc discharge plasma CVD diamond have similar strength that are almost half as much as that of sintered diamond.

In polycrystalline material like CVD diamond, grain boundaries, pores, grain shape and size distributions all

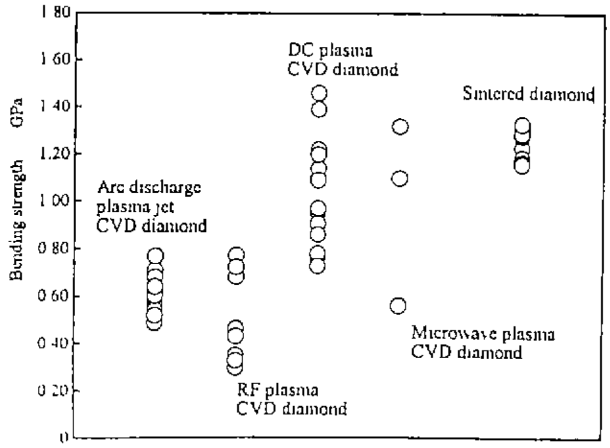

Fig. 3. Bending strength of CVD and sintered diamonds.

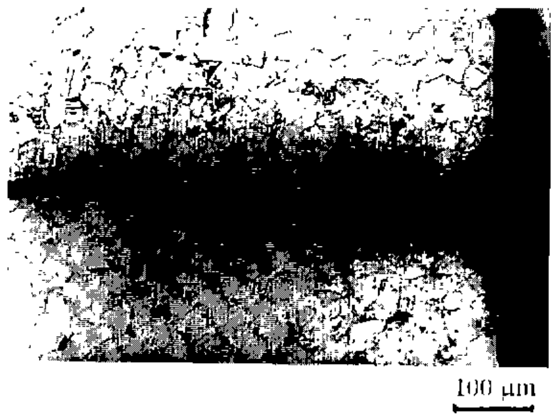

Fig. 4. Fracture mode of arc discharge plasma jet CVD diamond.

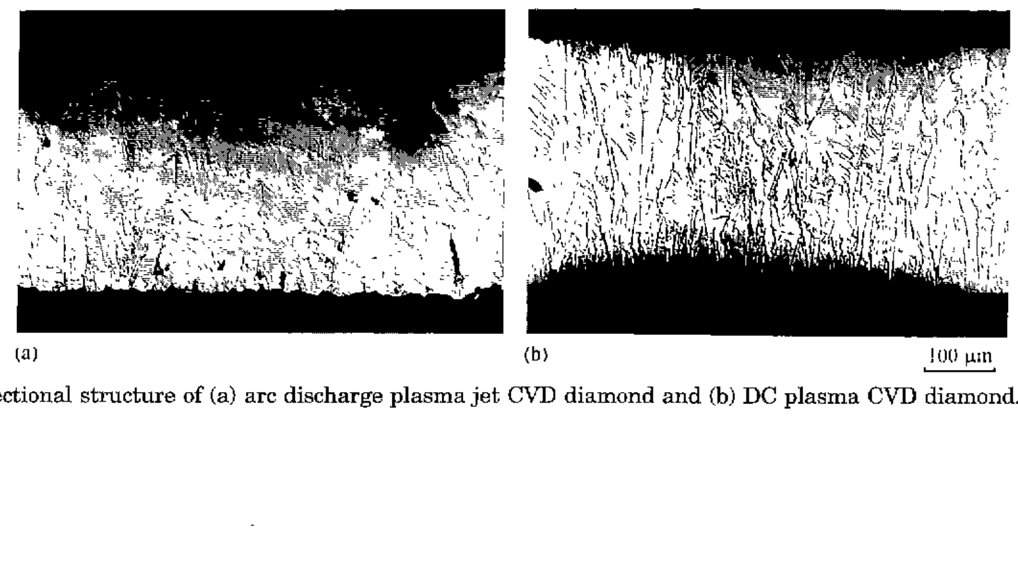

Fig. 5. Cross sectional structure of (a) arc discharge plasma jet CVD diamond and (b) DC plasma CVD diamond.

contribute to their strength. Thus, growth of CVD diamonds has been investigated by observing their structure. Figure 4 shows the fracture mode of arc discharge plasma jet CVD diamond. As the fracture path progresses independently of grains and grain boundaries, the strength of grain boundaries seems not to be inherently lower.

Cross sectional structure of arc discharge plasma jet CVD diamond and DC plasma CVD diamond are shown in Fig. 5. Arc discharge plasma jet CVD diamond consists of large grains and contains pores at an order of 10 μm. The other hand, DC plasma CVD diamond is composed of smaller grains without spacing. It is thought that higher strength of DC plasma CVD diamond occurs due to the close and fine structure. This indicates that CVD diamond consists of smaller grains without vacant spaces attains higher mechanical strength.

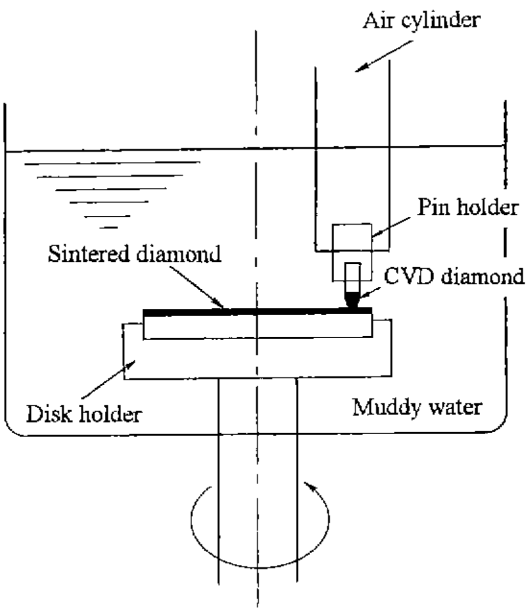

Fig. 6. Schematic diagram of friction testing set-up.

III. Wear Resistance

Wear resistance of CVD diamond has been investigated supposing that CVD diamond is applied to bearings installed in roller bits which are used for digging slim holes to obtain petroleum. This bearings are used under extremely high pressure of 20~50 MPa and conventional types are easily damaged when it is exposed into muddy water.

Figure 6 shows a schematic diagram of the friction testing method in muddy water. Wear resistance of CVD diamond has been estimated by the pin-on-disk type testing. A tungsten carbide pin coated with CVD diamond was fixed to the holder and pressed to a sintered di-

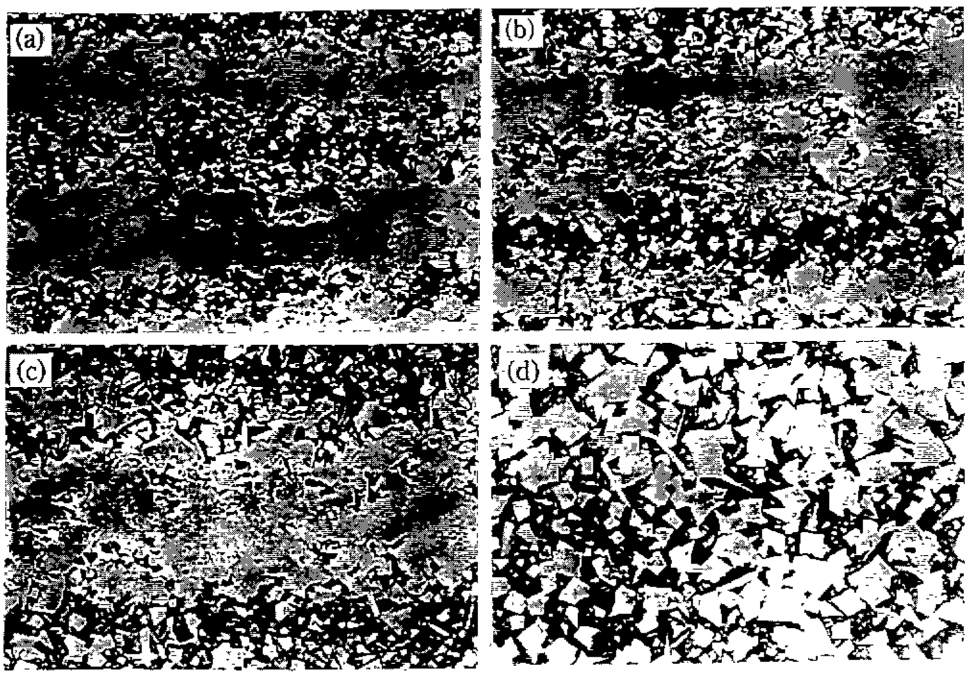

Fig. 7. Wear mode of (111) oriented CVD diamond at thickness of (a) 5 μm, (b) 10 μm, (c) 20 μm and (d) 30 μm.

Table 2. Components Rate of the Muddy Water

H_2O	Telgel	KCl	KOH	Regunate K	Telpolimer (L)	Astex (S)	A-1 heavy oil	Balite
100 cc	2 g	4 g	1 g	4 g	0.3 g	1.5 g	3 cc	60 g

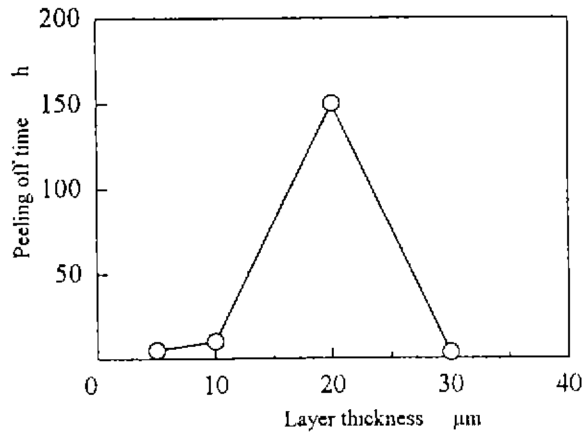

Fig. 8. Layer thickness versus peeling off time.

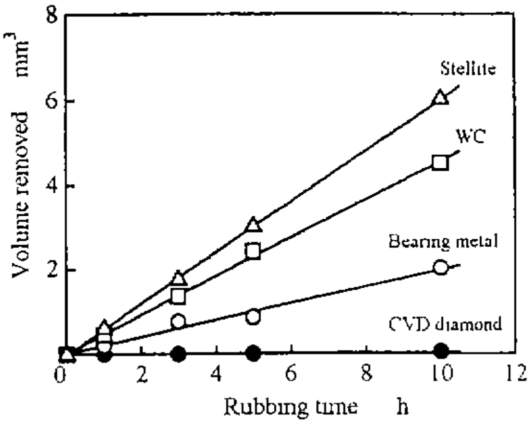

Fig. 9. Abraded volume rates stellite, WC alloy bearing steel and CVD diamond.

amond disk using an air cylinder. The rotational speed of the sintered diamond disk and the pressure applied to the pin were 50 m/s and 20 MPa. respectively.

Table 2 shows the components of the muddy water. The specific gravity and pH are 1.45 and 10.5 respectively.

CVD diamond was coated by hot filament CVD[6] and eight test pieces oriented (111) and (100) were prepared of which thickness are 5, 10, 20 and 30 μm. Grain sizes on growth side of CVD diamond films increase from 2 to 10 μm as the thickness increases.

Figure 7 shows the wear mode of (111) oriented CVD diamond after friction time of 3 hours. The projection of grains are rubbed off and flat areas occur. The abrasion rate of the thinner CVD diamond that consists of smaller grain seems to be higher, and the same wear mode was observed in (100) oriented CVD diamond. The defference in orientation were not observed.

The relation between layer thickness of CVD diamond oriented (111) and their peeling off time is shown on Fig. 8. Maximum peeling off time occurs when layer thickness is 20 μm. This suggests that thinner layer cannot withstand the frictional stress, and chipping easily occurs in thicker diamond. Thus optimum thickness is needed to avoid these problems that cause peeling off of CVD diamonds in short time. From our experiments, we conclude that the optimum layer thickness of CVD diamond is around 20 μm to achieve long life-time wear resistance.

Figure 9 shows the differences of abraded volume in stellite, WC alloy, bearing steel and CVD diamond CVD diamond indicates extremely higher wear resistance than that of other materials. Although WC is harder than bearing steel, it is abraded at higher rates because cobalt corrodes in alkali muddy water. Stellite that has almost equal hardness to bearing steel is also abraded because of corrosion of tungsten.

IV. Conclusions

Mechanical properties of CVD diamond have been discussed on bending strength and wear resistance.

1. CVD diamond consists of smaller grains without vacant spaces has higher bending strength.
2. The strength of the present CVD diamond is lower than that of sintered diamond.
3. The optimum thickness of CVD diamond layer is about 20 μm to prevent peeling off in short time.
4. The abrasion rates of CVD diamond in muddy water is extremely lower than that of Stellitc cemented carbide and bearing steel.

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