ASIATRIB 2002International Conference
JEJU ISLAND, KOREA

TRIBOLOGICAL PROPERTIES OF DLC FILMS SLIDING AGAINST DIFFERENT STEELS

M. SUZUKI[1] and A. TANAKA[2]

[1]*Joint Research Consortium of Frontier Carbon Technology, JFCC*
c/o AIST, Tsukuba Central 5, Ibaraki 305-8565, Japan
[2]*Research Center for Advanced Carbon Materials*
National Institute of Advanced Industrial Science and Technology (AIST)
Tsukuba Central 5, Ibaraki 305-8565, Japan

To study the effects of mating materials on the tribological properties of DLC films, we used a ball-on-plate reciprocating friction tester in dry air and mating materials of martensite stainless steel (hardened, annealed SUS440C), austenite stainless steels (SUS304), and bearing steel (hardened, annealed SUJ2). At a light load of 0.6 N, the friction coefficient always exceeded $\mu > 0.3$. Tribological properties of DLC film were still excellent above 0.6 N, except in sliding against annealed SUJ2. Analysis using micro-laser Raman spectroscopy showed that the difference between annealed SUJ2 and others materials appears mainly due to structural change in film.

Keywords: DLC film, mating materials, hardness, friction, wear, tribological property

1. INTRODUCTION

DLC films have good tribological properties such as low friction and high wear resistance. Film properties are complexly affected, however, by deposition methods and conditions, sliding conditions, mating materials, etc., [1,2] making it important to understand the nature of mating materials better. Studies on tribological properties of DLC films sliding against different mating materials have shown that these properties are related to mating material hardness [3,4]. However, the mechanisms of the effects of such factors on the tribological properties of DLC films are not well known.

In this study, the effects of mating materials on tribological properties of DLC films were determined using a ball-on-plate reciprocating friction tester in dry air and three species of steel balls with different hardness as mating materials.

2. EXPERIMENTAL

2.1 DLC film and mating material

DLC film was deposited on silicon wafers in CH_4 gas using RF plasma chemical vapor deposition (CVD). DLC film thickness and hardness were measured by a surface profilometer and a nanoindenter, respectively. DLC film was analyzed using micro-laser Raman spectroscopy and film hydrogen content measured using elastic recoil detection analysis (ERDA).

Mating materials were martensite stainless steel (hardened, annealed SUS440C), austenite stainless steel (SUS304), and bearing steel (hardened, annealed SUJ2). Their hardness was measured using a Vickers hardness tester.

2.2 Friction and wear tests

Tests were conducted using a ball-on-plate reciprocating tribometer. Friction force was monitored by a leaf spring with strain gages. The mating ball was a steel ball 4.76 mm in diameter. Prior to tests, specimens were cleaned with petroleum benzine and acetone in an ultrasonic cleaner and dried in a desiccator. Loads were 0.6-4 N (maximum Hertzian stress, 0.6-1.2 GPa), velocity 10 mm/s, and sliding distance 72 m. The atmosphere was dry air (<20% humidity).

The wear scar morphology of DLC films and mating balls were observed using optical microscopy. Films onto wear scars on mating balls and film wear tracks were determined using micro-laser Raman spectroscopy.

3. RESULTS AND DISCUSSION

Table 1 summarizes the hardness of various steel balls. SUS440C and SUJ2 steel balls were harder than SUS440C (annealed) and SUS304 and SUJ2 (annealed) steel balls. DLC film had a hardness of 18 GPa, a thickness of 400 nm, a roughness of Ra=0.74 nm, and a hydrogen content of 31 at%. Micro-laser Raman analysis yielded a typical spectrum of DLC film.

The effects of normal load on friction and wear in DLC film sliding on different steel balls is shown in Fig. 1. With the exception of a light load (0.64 N), the friction coefficient and specific wear rate decreased slightly with increasing normal load. At a light load of 0.64 N, the friction coefficient was always high (μ=0.3-0.35) but wear of DLC film was too small to be detected. No difference in friction or wear was seen between hard (SUS440C and SUJ2) and soft (SUS304) steel. These test conditions did not clarify the effects of mating ball hardness and species although the effect of a normal load was clear.

Figures 2 and 3 show the friction coefficient and the specific wear rate of DLC films depending on the hardness of SUS440C and SUJ2, respectability. In SUS440C having different hardness, tribological properties were similar to those in Figs. 2 and 3, with a high friction coefficient and low wear occurring under a light load. Above 0.64 N, low friction coefficient and good antiwear were obtained. With SUS440C, the difference in friction and wear between hardened, annealed balls was clear: the friction coefficient of DLC film against annealed SUJ2 was high value, 0.3-0.45 under a wide range of load conditions. Tribological properties of DLC film may thus be affected by a property change accompanying a hardness change in annealing rather than being affected by mating ball hardness or species.

Figure 4 shows the micro-laser Raman spectra of wear scars on hardened, annealed SUJ2 balls. With annealed SUJ2, micro-laser Raman spectra of materials transferred to the ball appeared shifted due to a change in the DLC structure. Such change was also seen at a load of 0.6 N. These changes appeared to be correlated with a difference in tribological behavior.

4. CONCLUSION

In this study, the effects of mating materials on tribological properties in DLC films determined using a ball-on-plate reciprocating friction tester in dry air. Three species of steel balls with different hardness were used as mating materials. Neither the hardness nor the species of mating materials appeared to affect tribological properties, but the effects of load on tribological properties were clear. At a load of 0.64 N, the friction coefficient was always high. The friction coefficient in annealed SUJ2 was also high. Micro-laser Raman analysis suggested that the structure of materials transferred from DLC film to mating balls changed, and such a change appeared to cause the high friction coefficient.

5. ACKNOWLEDGMENTS

We thank Dr. M. Ko of the Korea Institute of Industrial Technology for film deposition. This work was supported by the Frontier Carbon Technology (FCT) project, which was consigned to the Japan Fine Ceramics Center (JFCC) by the New Energy and Industrial Technology Development Organization (NEDO).

6. REFERENCES

[1] Grill, A., "Review of the tribology of diamond-like carbon," Wear, Vol. 168, pp. 143-153, 1993

[2] Grill, A., "Tribology of diamond like carbon and related materials: an updated review," Surface and Coating Technology, Vol. 94-95, pp. 507-513, 1997

[3] Liu, H., Tanaka, A. and Kumagami, T., "Influence of sliding mating materials on the tribological behavior of diamond-like carbon films," Thin Solid Films, Vol.352, pp. 145-150, 1999

[4] Tanaka, A. and Chul, NA. B., Tribological study on DLC films depending on the hardness of mating materials and applying loads, "Proceedings of 2nd World Tribology Congress," The Austrian Tribology Society, 2001

Table1 Specimen hardness

Steel ball		Vickers hardness ($H_{v0.5}$)
SUS440C	Hardened	830
	Annealed	230
SUJ2	Hardened	880
	Annealed	210
SUS304		270
DLC film		1800*

*: From nanoindenter

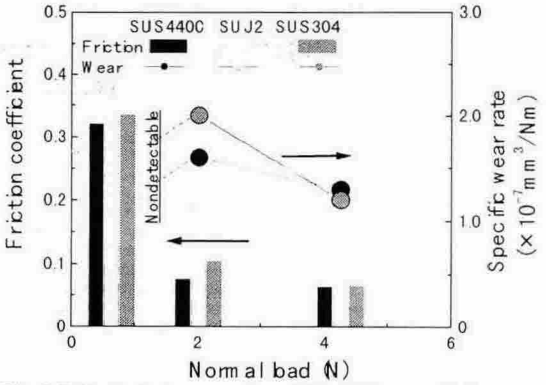

Fig. 1 Tribological properties of DLC film with different mating materials

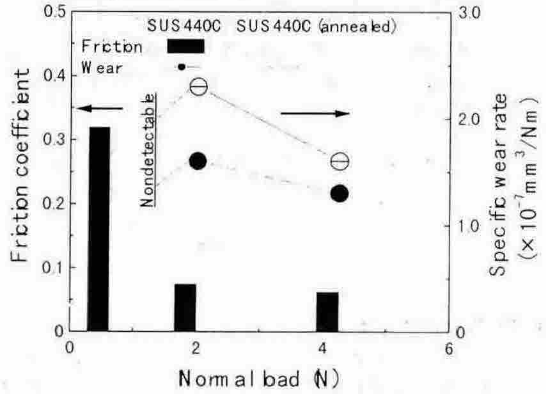

Fig. 2 The effect of SUS440C hardness on tribological properties of DLC film

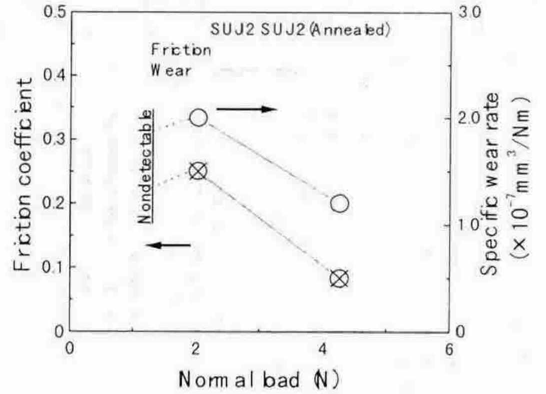

Fig. 3 The effect of hardness of SUJ2 on tribological properties of DLC film

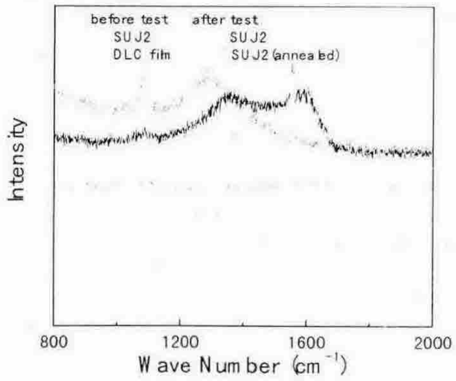

Fig. 4 Micro-laser Raman spectra of SUJ2 ball and DLC