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Tribological Characteristics of Diamond-like Carbon Films Based on Hardness of Mating Materials

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This study made use of four kinds of mating balls that were made with stainless steel but subjected to different annealing conditions in order to achieve different levels of hardness. In all load conditions, testing results demonstrated that the harder the mating materials, the lower the friction coefficient was. Conversely, the high friction coefficient found in soft martensite balls appeared to be caused by the larger contact area between the DLC film and the ball. Raman Spectra analysis showed that the transferred materials were a kind of graphite and that the contact surface of the DLC film seemed to undergo a phase transition from carbon to graphite during the high friction process.

Keywords : Diamond-like carbon, Tribology, Hardness of mating material, Material Transfer

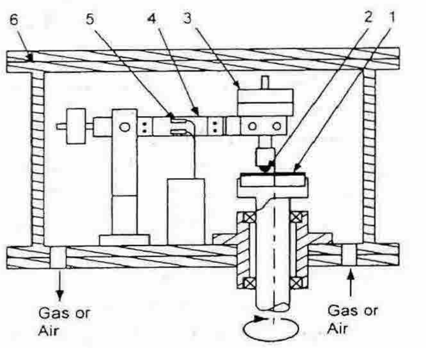
1. INTRODUCTION

Most of the previous works on DLC films have been concerned with their various properties or deposition [1-2]. However, it is also essential to take into consideration how the tribological properties of DLC films are affected by the properties of mating materials [3] since it is the hardness of the mating materials that is one of the important factors in determining the tribological properties of DLC films [4].

2. EXPERIMENTAL DETAILS

Tribological tests were conducted with the use of a rotating-type ball on disk friction tester with dry air. Fig. 1 illustrates the friction tester.

The thickness of the deposited film was 0.4 - 0.5 μm, and average surface roughness was about 1 nm. Four kinds of stainless balls (ϕ=4.8mm) shown in Table 1 were used as mating specimens. Mating balls have gone through different annealing conditions to achieve different levels of hardness. The load applying to DLC films are 0.64N, 1.28N, 1.92N, 3.20N and 4.48N for each mating ball.



1. DLC Specimen
2. Ball Specimen
3. Weight
4. Leaf Spring
5. Strain Gauge
6. Gas Vessel

Fig. 1 Schematics of Friction Tester

3. RESULTS AND DISCUSSION

Fig. 2 illustrates some comparative data of several friction coefficient results, depending on the hardness of mating balls, when load conditions are at 0.64N, 1.92N, 3.20N and 4.48N. As observed under all load conditions, softer mating materials resulted in a higher friction coefficient using martensite-mating balls. This is because the contact area was enlarged during friction experiments. On the other hand, friction coefficients were lower with austenite balls. Regardless of a mating ball's hardness, the maximum friction coefficient is achieved with a load condition of 1.92N. The effects of the transfer of material between DLC films and mating balls are shown in load conditions above 1.92N. Below 1.92N, the increase in contact area significantly affects the friction coefficient. In this case, tendency of the friction coefficients seems to follows the ploughing effect considering on wear profiles and material properties (hard and brittle) of DLC film [4]. Above 1.92N however, material transfer from DLC to the mating ball is a dominant factor that reduces friction coefficients. In this case, friction coefficients are less affected by load conditions. It is a well-known fact that both the wear rate of DLC films and the friction coefficient decrease because of the transfer of carbon-like materials from DLC films to the mating balls. DLC films undergo phase transformation during the rubbing process[5]. The Raman Spectra analysis can determine what the transferred material from the DLC films to the mating balls is.

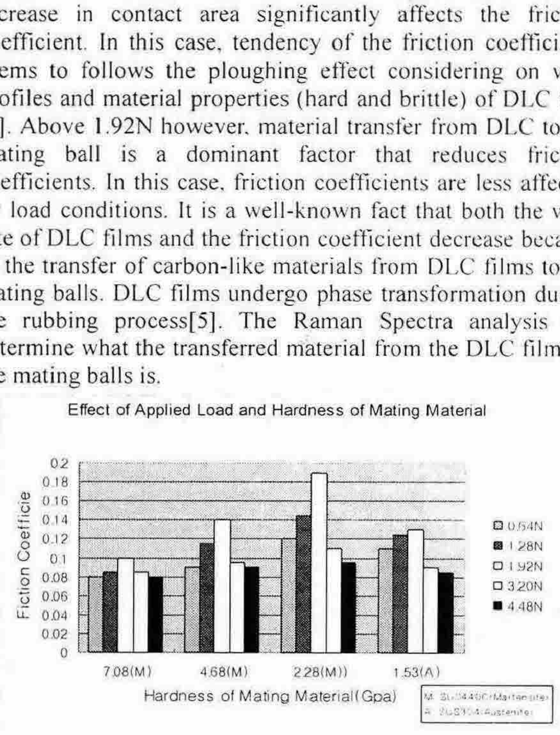


Fig. 2 Effect of Hardness of Mating Balls

Fig. 3 traces wear morphology of mating balls after a friction test. It also proves that the softer the mating ball, the wider the wear trace in martensite mating balls is. A wide contact profile on the DLC film and wide wear trace on the mating ball mean a wide contact area. Thus, it may be deduced that the softer the mating ball is, the wider the contact area will be. Conversely, the wear track and the wear trace profile are observably smaller with an austenite ball.

Based on the applied load and hardness of mating balls, Fig. 4 shows calculated wear rates of mating balls. As the load increases, wear rate of mating balls become large.

Fig. 5 shows wear rates of DLC films depending on the hardness of mating materials and the applied loads. The tendencies of wear rates are similar to the tendencies of friction coefficients in showing the peak point of wear rate. However, the load at maximum wear rate shifts to 1.28N as mating balls soften (2.28Gpa to 1.53Gpa). This shift can be considered as an effect in the transfer of materials owing to an increase of friction. If friction increases, material transfer also increases while friction coefficients and wear rate decreases. At load conditions of 3.2N and 4.48N, wear rate decreases depending on the hardness of the mating balls and wear rates remain to be relatively smaller than light load conditions. With such heavy load conditions, material transfer could cover any mating ball regardless of its hardness.

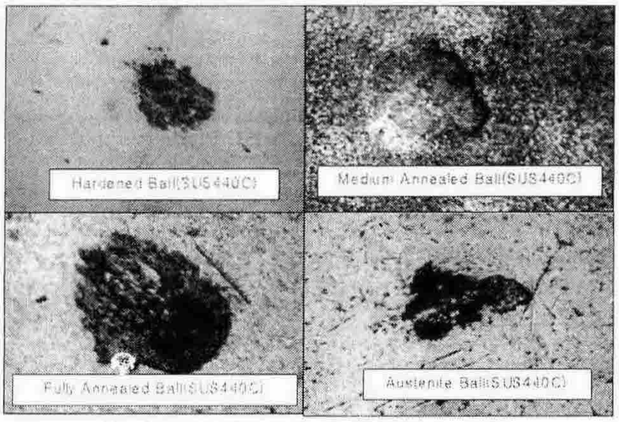


Fig. 3 Wear Morphology on Mating Balls

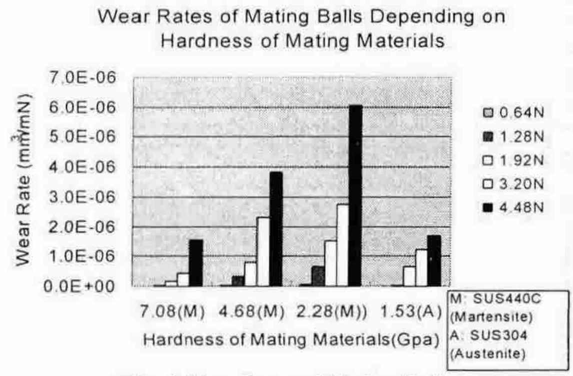


Fig. 4 Wear Rates of Mating Balls

Fig. 5 shows the transferred materials on mating balls. At the end of the experiment, the contact surface of mating balls was fully covered with transferred materials from the DLC film. In this figure, the covered material is striped for observing purpose. As shown in the figure, the DLC film and mating ball do not actually touch as transferred materials are inter-laid between them.

Fig. 6 shows the Raman Spectra analysis of transferred materials on mating balls. The first peak to be analyzed was designated as SP3 carbon according to the reference spectrum table [9]. The second was SP^2 carbon. Transferred materials on mating balls that were shifted in the second peak proved to be graphite. Therefore, it may be concluded that the transferred material is graphite and that the contact surface of a DLC film is considered to have undertaken a phase transition from carbon to graphite.

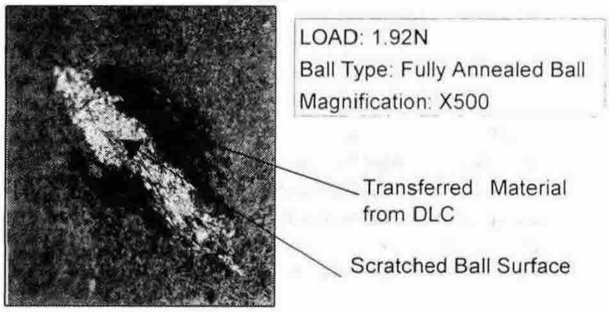


Fig. 5 Transferred Material on Mating Ball

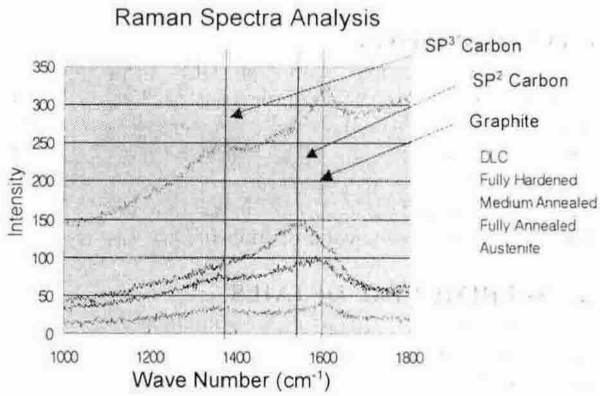


Fig.6 Raman Spectra Analysis (Load=1.92N)

4. REFERENCES

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