Proceedings of Malaysian International Tribology Conference 2015, pp. 14-16, November 2015

Low friction property of carbon overcoat DLC under boundary lubrication

T. Tokoroyama*

Faculty of Engineering Sciences, Akita University, 1-1, Tegata-Gakuenmachi, Akita, 010-8502, Japan.

*Corresponding e-mail: tokoroyama@gipc.akita-u.ac.jp

Keywords: Boundary lubrication; Carbon Overcoat; DLC

ABSTRACT – The surface protection by carbonaceous coating is becoming also common in several industries. We already know hard disk drive has been protected by very thin Diamond-Like Carbon and very few amount of lubrication. From the very low normal load condition to high, we have to consider how to reduce the wear amount of DLC itself, but also counter materials. In this study, we focused on low friction coefficient and low attack ability to the counter materials under boundary lubrication condition. Several kinds of DLC were reported and it showed very low friction coefficient in special condition (in high vacuum, in dry nitrogen etc.), however, it was also difficult to achieve lower than 0.1 under ATF (Automatic Transmission Fluid). From the hypothesis of solid lubrication, low friction coefficient will take place if we apply a soft material on a hard material. We tried to clarify the effect of carbon overcoat on DLC coating slid in ATF under boundary lubrication condition. The DLC coating was synthesized on steel alloy disk by sputtering. The thickness of as-deposited DLC was approximately 1 μm, and we gave carbon overcoat on it as 0.3 μm. The surface roughness of DLC and DLC with carbon overcoat was approximately 6.2 nmRa and 1.8 nmRa respectively. The wear scar on SUJ2 ball was observed by optical microscope and SEM, then specific wear rate was compared. The friction coefficient of DLC with carbon overcoat showed around 0.09 was smaller than DLC of 0.2. Moreover, the specific wear rate of SUJ2 ball slid against DLC with carbon overcoat was approximately 1.7 x 10^{-6} mm^3/Nm, which was smaller than 2.8 x 10^{-6} mm^3/Nm of DLC.

1. INTRODUCTION

Diamond-Like Carbon (DLC) is one of the potential candidates to reduce friction coefficient by its smooth surface, high hardness rather than almost metals, low adhesion due to its chemical inertness and so on. The most interesting point of DLC is its structure which is able to be varied by friction and wear at the interface of sliding with/without lubrication. In some cases, lubrication denied a construction of transfer layer on counter material or unenhanced of structural changing, then, friction coefficient did not decrease. From the view point of boundary lubrication, solid lubricant property is also important such as the mentioned situation. In the automobile fields, some gears in the automobile are immersed in ATF (Automobile Transmission Fluid) lubrication to cool the sliding parts (because of friction heat generated) and eliminate wear particles. Several papers reported friction of DLC under ATF such as to prevent shudder as previous study [1], to evaluate damages, spalling or cracking and so on as previous study [2], to clarify frictional behaviour include tribochemical reaction and it induced tribochemical layer on the DLC or mating materials as previous study [3-5]. If the friction condition becomes sever than before at boundary lubrication, the performance of solid lubrication is assumed to be important as much as tribochemical layer. One of the methods to obtain solid lubricant property was assumed to add a thin and soft overcoat on a hard material as previous study [6]. Therefore, in this study, we investigated the possibility to reduce friction coefficient of DLC and wear amount of mating materials by using carbon overcoat onto the DLC under ATF boundary lubrication condition. Amorphous carbon (a-C), hydrogenated amorphous carbon (a-C:H), carbon overcoat on a-C (C.O.) and ta-C tetrahedral amorphous carbon (ta-C) were the test materials slid against a SUJ2 stainless steel ball at room temperature, and specific wear rate of the ball was calculated from optical microscope observation.

2. EXPERIMENTAL

The all coatings were deposited on SCr420H with 100 nmRa of surface roughness. The a-C was synthesized by magnetron sputtering method to approximately 1.0 μm thickness. The C.O. coating was prepared onto the a-C coating as additional layer within a consecutive procedure. The thickness of C.O. was approximately 0.3 μm. On the other hand, the a-C:H coating was synthesized by PECVD (plasma enhanced chemical vapor deposition) method to approximately 3.0 μm thickness. The mating material was SUJ2 ball with 6.35 mm diameter with 40 nmRa surface roughness.

The friction test was performed by Ball on Disk type friction tester. We applied approximately 8.0 N normal load (the Hertzian contact pressure was approximately 1.3 GPa) and 0.05 m/s sliding speed, respectively. Before the friction test, the SUJ2 balls were cleaned by acetone at 15 min. in ultrasonic bath. The ATF lubricant (0.045 Pa*s@25 degree C) was prepared and we immersed each sample and ball in the lubricant, then friction test was carried out reaching to 10000 cycles. After the friction tests, ball samples were observed by optical microscope to calculate wear

© Malaysian Tribology Society

amount and specific wear rate with following formula, V/WL, where V is wear volume of ball, W is normal load and L is sliding distance of ball. The hardness of each coating was measured by nano-indentation test (Elionix, ENT-1100a) with 200 μN of normal load. The 12 positions were measured, a highest and a lowest values and noised values were eliminated and then average was calculated from the remainder. The EDS analysis was performed by JEOL JCM-5700NU with 20 kV accelerated voltage. The main elements to analyze were carbon, oxygen and phosphate.

3. RESULTS AND DISCUSSION

The friction test results are shown in Fig. 1 (a) as a-C, Fig. 1 (b) as a-C:H, Fig. 1 (c) as C.O. and Fig. 1 (d) as ta-C, respectively. The friction coefficient of a-C was approximately 0.22 at the beginning, then, it vibrated among 0.14 to 0.28. This frictional behaviour was seemed shudder. On the other hand, in the case of friction coefficient of a-C:H, Fig. 1 (b) shows that the value was around 0.26 at the beginning, then, it gradually decreased to 0.19 with small vibration rather than a-C coating. Then, the friction coefficient of C.O. was approximately 0.1 at the beginning, then, it reached down to 0.09 as average value. This friction coefficient means approximately half of average value from a-C coating. Finally, the ta-C (Fig. 1 (d)) shows higher friction coefficient rather than other coatings.

After 10000 cycles sliding, the balls were observed by optical microscope. The pictures are shown in Fig. 2 (a) to (d). Each diameter of wear scar was measured and specific wear rate of ball was calculated. It was revealed that if we applied C.O. coating on a-C, the specific wear rate became approximately 2/3 (2.8 to 1.7 x 10^{-6} mm^3/Nm). The reason of low specific wear rate was assumed to the influence of DLC hardness. The nano-indentation hardness and surface roughness of before and after friction each surface was not much difference. The hardness values include approximately 10 % variation range, therefore, the values of before and after friction were assumed to be same for each sample. It was clear that C.O. coating was approximately 2/3 of hardness in comparison to a-C. Therefore, the C.O. coating had a property of lower attack ability than a-C although both coatings were deposited by same equipment and also same synthesis procedure.

4. SUMMARY

The friction coefficient of DLC under ATF boundary lubrication condition was investigated with a-C, a-C:H and C.O. (Carbon Overcoat on a-C). The friction coefficient of a-C varied from 0.14 to 0.28 which seemed to be shudder. The value of a-C:H did not vary like a-C coating, and the average was 0.19. On the other hand, the C.O. coating showed 0.09 with small variation unlike a-C coating. The specific wear rate of C.O. coating on a-C was approximately 1.7 x 10^{-6} mm^3/Nm which was 2/3 of a-C.

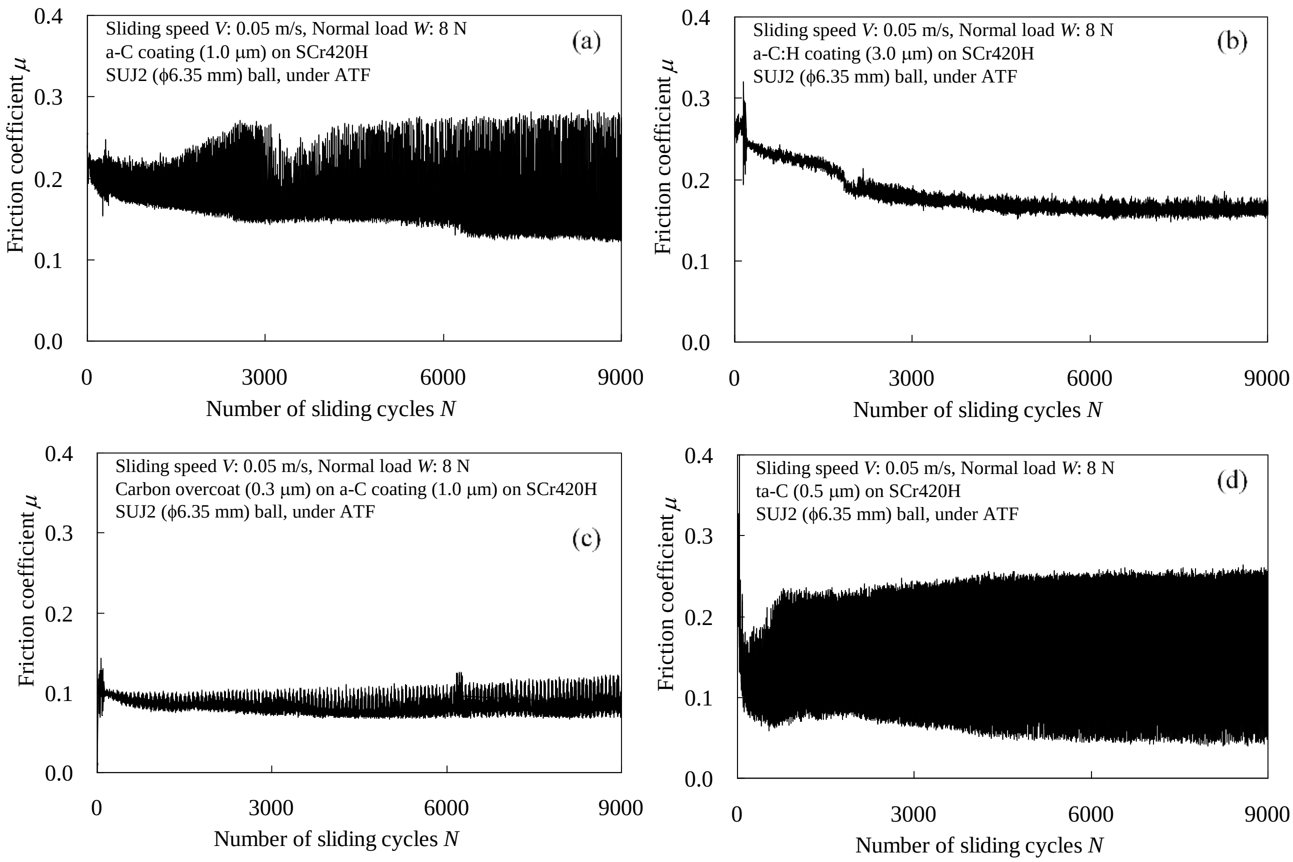

Figure 1 The friction coefficient variation as a function of number of sliding cycles, (a) a-C, (b) a-C:H, (c) carbon overcoat on a-C and (d) ta-C.

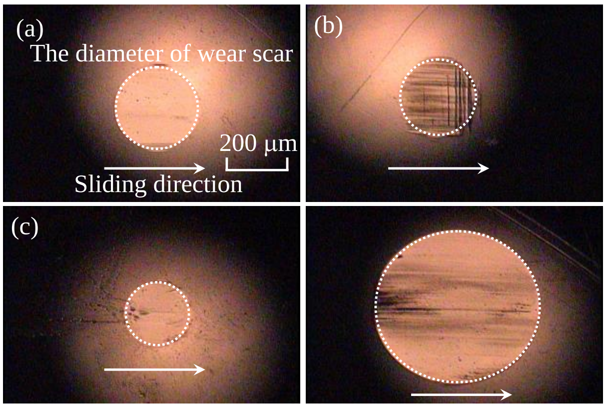

Figure 2 Optical microscope images of the SUJ2 ball after friction test against (a) a-C, (b) a-C:H, (c) carbon overcoat on a-C and (d) ta-C.

5. REFERENCES

[1] J.Ando, T.Ohmori, A.Murase, N.Takahashi, T.Yamaguchi, and K.Hokkirigawa, "Tribological properties of Si-containing diamond-like carbon film under ATF lubricarted condition", *Wear*, vol. 266, pp. 239-247, 2009.

[2] J.Ando, T.Ohmori, A.Murase, N.Takahashi, T.Yamaguchi, and K.Hokkirigawa, "Tribological properties of Si-containing diamond-like carbon film under ATF lubricarted condition", *Wear*, vol. 266, pp. 239-247, 2009.

[3] B. Podgornik, M. Sedlaced, and J. Vizintin, "Compatibility of DLC coatings with formulated oils", *Tribology International*, vol. 41, pp. 564-570, 2008.

[4] T. Yamaguchi, J. Ando, T. Tsuda, N. Takahashi, M. Tohyama, A. Murase, T. Ohmori, and K. Hokkirigawa, "Sliding velocity dependency of the friction coefficient of Si-containing diamond-like carbon film under oil lubricated condition", *Tribology International*, vol. 44, pp. 1296-1303, 2011.

[5] Z. Tang, and S. Li, "A review of recent developments of friction modifiers for liquid lubricants", *Current Opinion in Solid State and Materials Science*, vol. 18, pp. 119-139, 2014.

[6] H. Nyberg, T. Tokoroyama, U. Wiklund, and S. Jacobson, "Design of low-friction PVD coating systems with enhanced running-in performance – carbon overcoats on TaC/aC coatings", *Surface and Coatings Technology*, Vol. 222, pp. 48-54, 2013.