ASIATRIB 2002 International Conference
JEJU ISLAND, KOREA

Tribological properties of ultra-thin diamond-like carbon coating at various humidity

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This study concerns the tribological behaviors of ultra-thin DLC coating with 3 nm thickness deposited in a mixed gas of argon + 20 % hydrogen as a function of humidity. Reciprocating wear tests employing a micro wear tester were performed under various normal loads and relative humidity in air environment. The chemical composition of the original and worn surfaces were studied by Auger electron spectroscopy (AES). It showed that the ultra-thin DLC coating exhibited low friction with enough wear stability at low normal load (0.18 N) and its tribological behavior was strongly dependent on the humidity. The sample surfaces before and after the test were examined using atomic force microscopy (AFM). Capillary force and meniscus areas were discussed in order to explain the influence of humidity on the friction force.

Keywords : DLC coating; Auger electron spectroscopy; Atomic force microscopy; Topography image; Capillary force ; Meniscus area.

1. Introduction

Due to the superior mechanical and tribological properties, the diamond-like carbon (DLC) coatings are now widely used in various industrial applications, especially in magnetic storage devices and microelectro-mechanical systems (MEMS)[1-4]. It has been reported that the hydrogen content in coating structure and tribotesting conditions strongly influenced the friction and wear characteristics of these films [1,4,5-7]. The role of relative humidity (RH) was discussed through its contribution to formation of meniscus around contacting asperities between two surfaces [10,11]. The capillary force directly affected to friction property of the film. In this study, tribological properties of an ultra-thin DLC coating with 3 nm thickness, deposited in a mixed gas of argon + 20 % hydrogen, was investigated under various normal loads and relative humidity.

2. Experiment

DLC-coated flat specimens with 3nm film thickness were prepared by DC sputtering deposition technique. The coating layer was grown up by sputtering of a graphite target in a mixture gas of argon and 20 % hydrogen plasma. Reciprocating wear tests against 3mm diameter Si_3N_4 balls were performed at normal loads of 1.8 N and 0.18 N. The tests were conducted at 2.5 %, 50 %, and 90 % of RH with a sliding speed of 4.44 mm/s and a stroke length of 3 mm. The temperature was maintained between 28-31°C during the tests. The original and worn surfaces were examined using AES for chemical element analysis and AFM for surface feature.

3. Results and discussions

Figure 1 displays the frictional behavior of the DLC coating tested at 0.18 N. At 2.5 % RH, the coefficient of friction was kept a steady low value until ~ 375 cycles beyond which failure of the coating initiated. Repeated test runs at this condition for extended number of sliding cycles (>800 cycles) showed that coating layers were rapidly removed. In the case of 50 % RH, the test stopped at 550 cycles (a) showed the initiation of coating damage

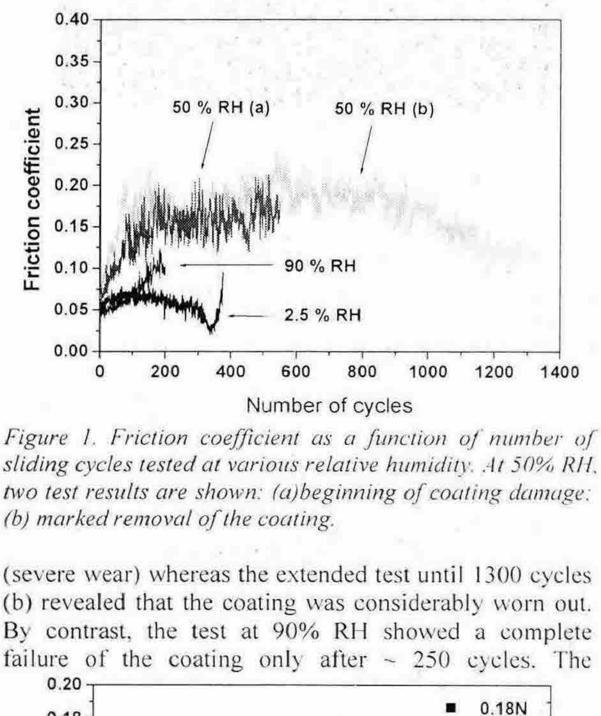

Figure 1. Friction coefficient as a function of number of sliding cycles tested at various relative humidity. At 50% RH, two test results are shown: (a)beginning of coating damage; (b) marked removal of the coating.

(severe wear) whereas the extended test until 1300 cycles (b) revealed that the coating was considerably worn out. By contrast, the test at 90% RH showed a complete failure of the coating only after ~ 250 cycles. The

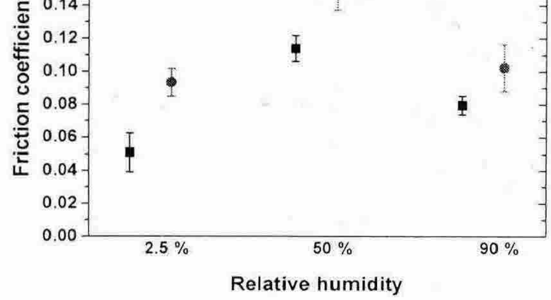

Figure 2. Friction coefficient of ultra-thin DLC coating at three different relative humidity.

summary of friction coefficient at various relative humidity at 0.18 N was displayed in figure 2. The coefficient of friction was within 0.04 ~ 0.062 for the test at 2.5 % RH and slightly increased to the range 0.07 ~ 0.085 at 90 % RH, whereas it reached a much higher value between 0.105 ~ 0.125 at 50 % RH. The results obviously demonstrated the influence of relative humidity on the tribological behavior of the coatings. The coefficient of friction was higher at 50 % RH compared to those at 2.5 RH % and 90 % RH. In the case of the test with 1.8 N load, we observed the same trend as that with 0.18 N.

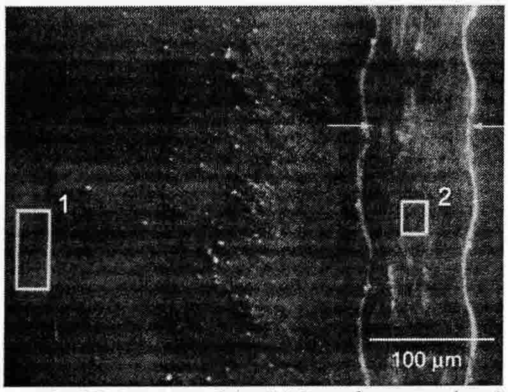

Figure 3. SEM image of the DLC surface tested at 0.18 N load under 50 % RH. Area #1 showed the original surface and #2, inside the wear track.

Figure 3 shows the SEM image of the original and worn surfaces tested at 50 % RH for 1300 cycles. The dark region in wear track indicated that the coating still remained although wear of the coating has considerably been undergone. Figure 4 shows the AES depth profiles

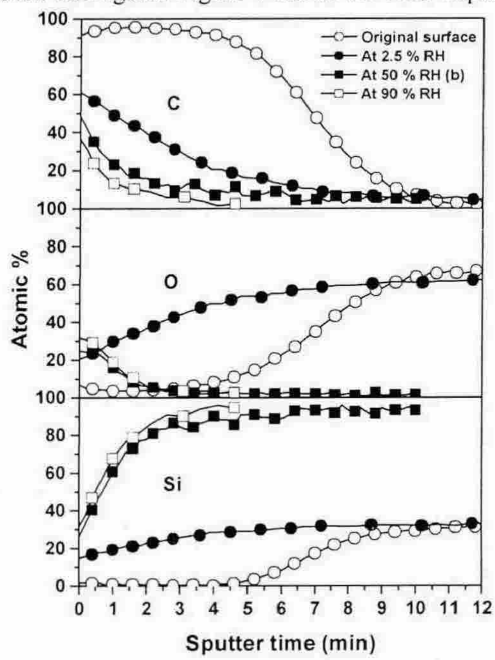

Figure 4. AES results for depth profiles of different chemical elements for original and worn surfaces.

of various chemical elements for representative regions in original and worn surfaces at three different relative humidity conditions. In the case of 2.5 % RH, the carbon composition was relatively higher, indicating its greater thickness than the other two humidity conditions. The presence of carbon composition inside the wear track at 50% RH confirmed that the coatings was not completely removed until 1300 cycles. At 90% RH, the carbon content was the lowest as the coating was most severely worn out only at 250 cycles. Less rapid decrease of carbon along the depth for 2.5 % RH, comparing with those at higher RHs, confirmed smallest damage of the coating at 2.5 % RH. The variation of silicon and oxygen compositions as a function of sputter depth also explained the difference in the wear severity of the coatings at different humidity. As this coating was not hydrophobic (contact angle, 68.3°), the influence of capillary force on friction force might be significant at high humidity. At 50 % humidity, the meniscus areas were formed around contacting asperities. The friction coefficient was higher due to the increase of capillary force in response to the increase of meniscus area. In the case of 90 % RH, a water layer might be formed between two surfaces and reduced the shear stress when sliding, leading to the decrease of friction coefficient (figure 2).

This experimental study demonstrated that the sputter-deposited 3nm thick DLC coating exhibited a good friction property particularly at low normal load and at low relative humidity. The influence of humidity on the friction behavior was confirmed to be of significance.

Acknowledgement

This work is supported by the National Research Laboratory Program of the Korean Ministry of Science and Technology

References:

[1] B. Bhushan; Diamond and related materials 8 (1999) 1985-2015.
[2] Modern tribology handbook, volume two: Bharat Bhushan editor-in-chief; CRC press (2000) 871-900.
[3] Principles and Applications of Tribology: Bharat Bhushan; Wiley Interscience , New York 1999.
[4] Molecular-scale tribology of amorphous carbon coatings: Effects of film thickness, adhesion, and long-range interactions; G.T. Gao, Paul T.Mikulski, and Judith A.Harrison; JACS Articles;2001.
[5] A.Erdemir; Surface and Coatings Technology 146-147 (2001) 292-297.
[6] C.Donnet; Surface and Coatings Technology 100-101 (1998) 180-186.
[7] A.Grill; Surface and Coatings Technology 94-94(1997) 507-513.
[8] E.Liu, B.Blanpain, J.-P. Celis, H.-S. Tan, B.-K. Tay, L.-K. Cheah, J.R. Roos; Surface and Coatings Technology 106 (1998) 72-80.
[9] J.Koskinen, D.Schneider, H. Ronkainen, T. Muukkonen, S. Varjus, P. Burck, K. Holmberg, H.-J. Scheibe. Surface and Coatings Technology 108-109(1998) 385-390.
[10] Yakov I.Rabinovich, Joshua J.Adler, Madhavan S.Esayanur, Ali Atal, Rajiv K.Singh, Brij M. Moudgil: Advances in Colloid and Interface Science 96 (2002) 213-230.
[11] X.Xiao and L. Qian; Langmuir 16 (2000) 8253-8158.