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Comparisons of tribological property of a-C, a-CN_x and BCN coatings sliding against SiC balls in water

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Abstract

Amorphous carbon-based coatings such as a-C, a-CN_x and BCN coatings were deposited on SiC disks using ion beam assisted deposition (IBAD). The friction and wear property of these three carbon-based coatings against SiC balls were evaluated using a ball-on-disk tribo-meter in distilled water. The lowest mean steady-state friction coefficient of 0.015 was obtained for the a-CN_x/SiC tribo-pair, while the largest mean steady-state friction coefficient of 0.09 was obtained for the a-BCN/SiC tribo-pair. Furthermore, BCN coating and SiC ball in a-BCN/SiC tribo-pair exhibited the largest specific wear rates, whereas the SiC ball had the lowest wear rate as sliding against a-CN_x coatings. This indicated that the alloy elements such as N and B have different influences on the stability of the coatings in water, and thus affected the tribological property of carbon-based coatings in water.
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1. Introduction

Currently, the leakage of lubricative oil from journal bearings or mechanical seals always makes the natural environments polluted. To resolve the pollution of oil lubrication and save the energy sources, water lubrication has already been suggested for replacing oil lubrication in modern machine designs. Water-lubrication systems, however, have some tribological problems such as high friction, high wear and seizures. To overcome the above-mentioned problems, it is imperative to develop the new tribo-materials to meet the requirements of modern machine designs in water environment. Since Fischer et al. [1] found that Si_3N_4/Si_3N_4 tribo-pairs showed a friction coefficient of 0.002 in water at a sliding velocity higher than 60 mm/s, many scientists have already focused on the water-lubrication mechanism of structural ceramics such as SiC, Si_3N_4, Al_2O_3 and ZrO_2 as well as their composites [2–7]. Nevertheless, the high cost and difficult fabrication of engineering ceramics usually restrict their applications in industries. Recently, the water lubrication of carbon-based coatings such as DLC [8–15] and a-CN_x coatings [16–18] has already been investigated.

For the water lubrication of DLC coatings, the mutually contradictory conclusions have already been obtained. For example, Ronkainen et al. [10] have indicated that the hydrogenated a-C:H films suffered from severe wear as sliding against an alumnia pin in water, whereas Suzuki et al. [12–14] recently reported that the friction and wear properties of DLC films were not influenced by hydrogen content as sliding against hardened martensite stainless steel (AISI 440C) in water. For the effects of Ar, F, Si, Ti on the tribological properties of a-C:H coatings in water, Ronkainen et al. [8,10] have indicated that Ti or Si could improve the performance of a-C:H coatings in aqueous conditions. However, Tanaka et al. [14] recently reported that the friction coefficients of Ar-DLC, F-DLC and Si-DLC varied in the range of 0.07–0.1, and the specific wear rates of Ar-

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DLC, F-DLC and Si-DLC films were at a low level of 10^{-8} mm^3/N m, independent of the type of DLC films as they slid against stainless balls in water. Because they used the different mating materials in tests, the different friction and wear behavior may be understood.

For the a-CN_x coatings in water lubrication, Zhou et al. [16,17] have already reported that, as compared with self-mated SiC ceramic, the a-CN_x coatings could enhance the wear resistance of SiC ball and shorten the running-in period as sliding against SiC ball at the low or high velocities in water lubrication. When a-CN_x coatings slid against ceramic balls (SiC, Si_3N_4 and Al_2O_3) and steel balls (SUS440C and SUJ2) at 5 N and 160 mm/s in water, the friction coefficients of 0.01–0.02 were obtained as a-CN_x coatings slid against SiC and Si_3N_4 balls, while the large friction coefficients of 0.07–0.10 were acquired as a-CN_x coatings slid against Al_2O_3, SUS440C and SUJ2 balls [18].

The above review on DLC and a-CN_x coatings' water lubrication suggests that carbon-based coatings are the promising candidates for the sliding parts in water hydraulic systems. However, the comparison of friction and wear property among a-C, a-CN_x and BCN coatings in water under the same testing conditions has not yet been performed. In this study, the aim was to determine the friction and wear performance of above three carbon-based coatings and find which coating has the best tribological property as sliding against SiC ball in water.

2. Experimental procedures

2.1. Deposition of carbon-based coatings

Fig. 1 shows a schematic diagram of the main components of the IBAD machine (Hitachi Ltd, Japan), which consists of a cryogenically pumped chamber, a sputter deposition source, an electron beam evaporator, two ion guns for sputtering and mixing, respectively, and a substrate holder. The diameter of the ion beam irradiation area is about 80 mm. The substrate holder consists of a water-cooled copper plate and can be rotated at a speed of 4 rpm during deposition.

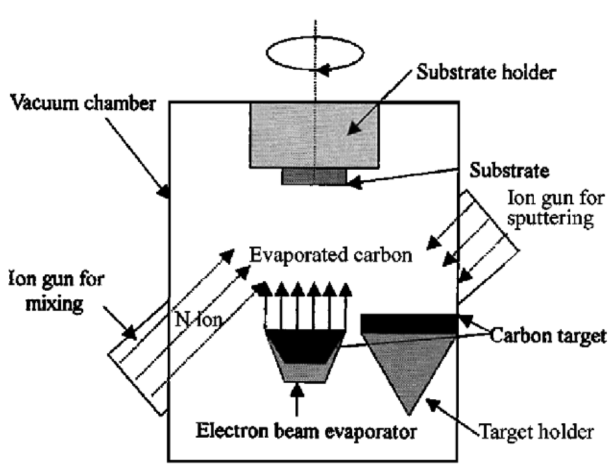

Fig. 1. Schematic diagram for ion beam assisted deposition apparatus.

Table 1
Roughness and mechanical properties of a-C, a-CN_x and BCN coatings

Name	R_a, μm	R_{max}, μm	H, GPa	E, GPa	H/E
a-C	0.011	0.025	34	440	0.08
a-CN_x	0.009	0.018	29	330	0.09
a-BCN	0.003	0.006	33	450	0.07

Prior to IBAD process, SiC disks and Si(100) wafers were ultrasonically cleaned in acetone and ethanol for 30 min. Then, a high purity carbon or boron carbide target was put into the electron beam evaporator and a substrate jig with SiC disk or Si(100) wafer was installed on the substrate holder with two screws. The vacuum chamber was subsequently evacuated to lower than 2.0×10^{-4} Pa. For further cleaning, SiC disk or silicon wafer surface was bombarded for 5 min by nitrogen ions generated at an accelerated voltage (a.v.) of 1.0 kV and an accelerated current density (a.c.d.) of 100 μA/cm^2. Later, the a-C coatings were made through sputtering carbon target with Ar ions. The sputtering Ar ions were formed at 1 kV (a.v.) and 100 mA (a.c.), whereas a-CN_x (a-BCN) coatings were deposited by mixing carbon (boron carbide) vapor and energetic N ions. Carbon (boron carbide) vapor was formed by heating carbon (boron carbide) target with electron beam evaporator. For a-CN_x coatings, the energetic nitrogen ions were produced at 1.5 kV (a.v.) and 90 μA/cm^2 (a.c.d.). But for BCN coating, the energetic nitrogen ions were generated at 2.0 kV (a.v.) and 60 μA/cm^2 (a.c.d.). The deposition rate of a-CN_x coatings was 20 Å/s, while that of BCN coatings was 5 Å/s. The thickness for all coatings was about 0.5 μm.

2.2. Measurement of coatings' surface roughness and mechanical properties

The coatings' surface roughness was measured by Surfcom-1500DX profilometer, and their mechanical properties were evaluated using a Nano Indenter ELIONIX. ENT-1100A. The experimental results were listed in Table 1.

2.3. Ball-on-disk wear test

Prior to each sliding test, SiC balls with the diameter of 8 mm and SiC disks covered with carbon-based coatings were ultrasonically cleaned in acetone and ethanol for 30 min. The ball-on-disk apparatus was described as the stationary SiC ball against the rotating disk (Fig. 2). All tests were done at a sliding speed of 160 mm/s and a normal load of 5 N, and the rubbing surfaces were submerged in distilled water. The contact point was 7.5 mm from the disk center.

The friction force was detected by load cell. The load cell voltage signals were recorded through an A/D converter using a PC. The wear scar diameter of SiC balls was

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