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Improvement of tribological characteristics under water lubrication of DLC-coatings by surface polishing

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ABSTRACT

To achieve a hydraulic power system, it is important to control tribology because water has a lack of lubricity. Therefore, coated surface is necessary under water lubrication. Diamond-like-carbon (DLC)-coating is known as a useful material because of its high hardness and low friction, therefore it can be used as a coating durable for the water lubrication. Deposition methods of DLC-coating are developed in various ways. Particles called "droplets" are observed on the surface of DLC-coating depends on deposition methods and it can affect friction and wear properties. In this study, DLC-coating was prepared using a multi-cathode unbalanced magnetron sputtering (UBMS) system. The surface was polished with diamond slurry solution and aero lap to remove droplets. DLC-coatings were evaluated by tribo-tests before and after polishing. It is considered that some surface modification occurred. Moreover, the results of tribo-tests show that friction coefficients became lower and more stable than before polishing. Although partial delamination was observed after tribo-tests without polishing, no appreciable wear was observed after polishing.

1. Introduction

In order to minimize the consumption of fossil fuels and mineral oils for preventing environmental destruction, use of water as a working fluid of hydraulic system instead of mineral oil is one of the solutions. Although the use of water has many advantages, the low lubricity of water has to be solved to develop the reliable water hydraulic systems. Therefore, tribology is the key technology to overcome the problem of water.

Some inorganic materials or coatings on metal surfaces are known to have a good lubricity under water lubrication [1,2]. For example, silicon nitride (Si_3N_4) and silicon carbide (SiC) show low friction in water environments [3–7]. In spite of having good lubricity under water lubrication, silicon nitride or silicon carbide cannot be applied to the commercial power systems due to the cost or their low machinability.

Diamond-like-carbon (DLC) is known as a low-cost coating durable not only for under dry condition but also for under water lubrication [8,9]. The authors have already reported that the DLC-coating showed low friction coefficient and sliding speed dependency of friction coefficient is very small under water lubrication [10]. There have been many reports on DLC-coating because it has unique properties, such as chemical inertness, mechanical, tribological and optical properties [11–17].

It has been known that small particles called "droplets" are occasionally observed on the surface of DLC-coatings. The degree of droplets formation varies depending on the deposition method. Especially, it is unavoidable in case of sputtering. Some experiments show that generation of droplets can be controlled using a filter [18]. However, degree of droplets formation is not always same even under the same condition and same deposition method, and in addition, it is unpredictable. From the tribological point of view, effect of the droplets should be clarified to maintain good lubricity.

In this study, the droplets were removed from DLC surface using two types of polishing method, and their effect on tribology under dry and water lubrication conditions was compared.

2. Experimental

2.1. Tribometer

Friction and wear properties were evaluated using a ball-on-disk tribometer. A flat disk was installed on a rotating shaft with a disk holder inside a cup. A ball was set in a ball holder. Heat-treated stainless steel (SUS630) ball having a diameter of 9.53 mm (3/8 in.) was used. In this study, the friction experiments were carried out

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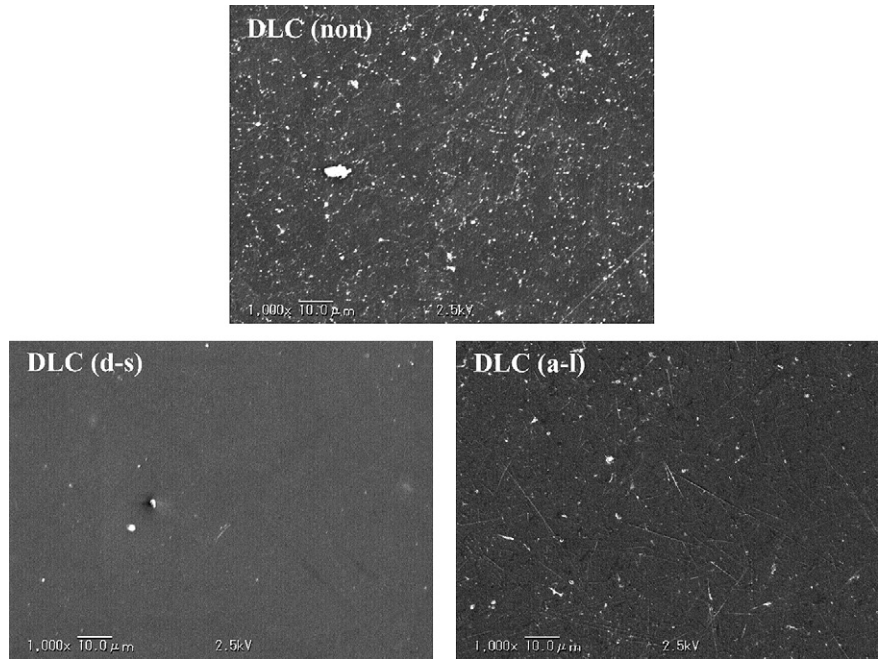

Fig. 1. SEM images of the surface of DLC-coatings after diamond slurry polishing DLC (d-s), after aero lap polishing DLC (a-l), and before polishing DLC (non).

under a constant axial load of 4.7 N and a sliding speed of 0.1 m/s. Total sliding distance in each experiment was fixed to 500 m except when DLC-coating was delaminated. All the friction experiments were carried out at room temperature and under dry or water lubrication condition. For water lubrication, the cup was filled with water and a disk in the cup was immersed in distilled water. Friction force was monitored during friction experiments with data acquisition rate of 5 Hz. All the results of the friction experiments shown in this paper are the averaged friction coefficient value obtained by a moving average method. Friction experiments were conducted several times in each experimental condition, and the typical experimental results that represented the result in each condition, are displayed in this paper.

2.2. Coated disk specimens

The DLC-coatings were deposited using a multi-cathode UBMS system. Details of this deposition instrument are described elsewhere [19]. Substrate material used in this study was a mirror polished precipitation hardened stainless steel disk. After the substrates were introduced in a vacuum chamber, the system was evacuated down to <1 mPa, followed by an Ar ion plasma etching process. The Cr metal layer was deposited on the substrate as a bonding layer and the Cr–C gradient layer was formed on the Cr layer by increasing the carbon content toward the surface. Finally, an approximately 500–600-nm thick DLC layer was deposited on top of the bonding and gradient layer under an Ar–CH_4 atmosphere (CH_4, 10 vol%). The substrate temperature and the bias voltage were approximately 200 °C and 100 V, respectively, during the deposition. Hardness was approximately 17 GPa. Hydrogen content was approximately 30 at%.

2.3. Surface polishing of DLC-coating disks

In order to remove droplets on the surface of coatings, two types of polishing method were used. One method was a typical wet polishing using diamond slurry aqueous liquid (particle size: 0.125 μm). The coating was polished for 400 s to remove droplets on the surface, followed by washing with ethanol by ultrasonic cleaning. Another method for removing droplets was a dry polishing called aero lap polishing. The aero lap polishing (Yamashita Works Co., Ltd.) is a lapping technique using shot particles with fine diamond powder on the surface, which are resilient and tacky containing a little water therein, blasted by air blow against the surface of target. In this paper, DLC-coatings with diamond slurry polishing, aero lap polishing and without polishing are tentatively defined as—DLC (d-s), DLC (a-l) and DLC (non), respectively.

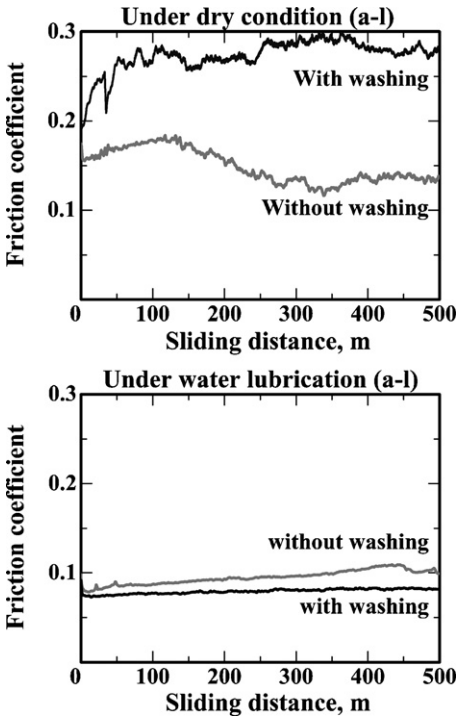

Fig. 2. Effect of washing treatment of DLC (a-l) on friction trace.