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Effects of water environment on tribological properties of DLC rubbed against stainless steel

M. Uchidate [a,*], H. Liu [a], A. Iwabuchi [a], K. Yamamoto [b]

[a] Department of Mechanical Engineering, Faculty of Engineering, Iwate University, 3-5, Ueda 4-chome, Morioka-shi, Iwate 020-8551, Japan
[b] Materials Research Laboratory, Kobe Steel Ltd., 5-5, Takatsukadai 1-chome, Nishi-ku, Kobe 651-2271, Japan

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Abstract

The effects of water environment on tribological properties of DLC against stainless steel were studied for development of the hydraulic pumps, valves and cylinders based on metal. A ball-on-disk tribotester was developed for detailed examination of water environment, such as temperature (20–80 °C), dissolved oxygen (0.01–8 ppm), water pressure (0.1–20 MPa) and dissolved ions. DLC was deposited on the disk by the unbalanced magnetron spattering system. Pure water and quasi-tap water were used to study the effects of dissolved ions. The results showed that temperature and dissolved ions have a major impact on friction and wear of DLC. EPMA, XPS and AES indicated that tribofilm on the metal surface, which consists mainly of C, O and Fe, plays important role for the phenomena.

Keywords: Water lubrication; DLC coatings; Friction; Wear; Elevated temperature

1. Introduction

Development of water hydraulic systems using metal based materials has been carried on as a national research project in Japan. In this development, combinations of DLC/stainless steel and DLC/brass are expected to achieve low friction and wear under water lubricated conditions because of the superior tribological properties in water [1–3]. Water used in the systems is to be tap water with no additives for ease of use and drainage. Hence, the properties of hydraulic fluid in the system vary depending on the region [4]. Also, the systems will be employed in various water environments in terms of temperature, dissolved oxygen and water pressure depending on use. Therefore, it is necessary to know the effects of factors mentioned above on tribological performance of DLC and counter materials.

DLC are thought to be relatively inert and stable in corrosive environment. For example, Yamaguchi et al. investigated friction and wear of DLC against alumina in pure water, 3 mass% NaCl solution and acidic solutions, such as HCl, HNO_3 and H_2SO_4 and showed that there is no significant change in pure water and these solutions [5]. On the other hand, Ronkainen et al. showed that water can be aggressive media for DLC rubbed by alumina [6].

This study focuses on the effects of water environment on tribological performance of DLC rubbed against stainless steel.

2. Experimental details

A ball-on-disk type tribotester, shown in Fig. 1, which can be operated under controlled water environment in terms of temperature (20–80 °C), water pressure (0.1–20 MPa) and dissolved oxygen (0.01–8 ppm) was developed for this study. About 1 L of water is filled in the autoclave and circulated at the rate of 20 mL/min by a high pressure pump throughout the tests. The autoclave is covered with the temperature chamber with a heating–cooling bath. The amount of dissolved oxygen in water is controlled by aeration of N_2 and O_2 gas in a reserve tank. Frictional force was measured by the torque meter attached to the driving shaft. Electrodes connected to the potentio-stat were also placed in the chamber for electrochemical measurement as shown in Fig. 1. Turning radius of the ball specimens is 13 mm.

Both the ball and disk specimens were made of AISI 630 stainless steel (Fe–17%Cr–4%Ni–4%Cu–1%Nb) hardened in

* Corresponding author. Tel.: +81 196 621 6417; fax: +81 196 621 6417.
E-mail address: uchidate@iwate-u.ac.jp (M. Uchidate).

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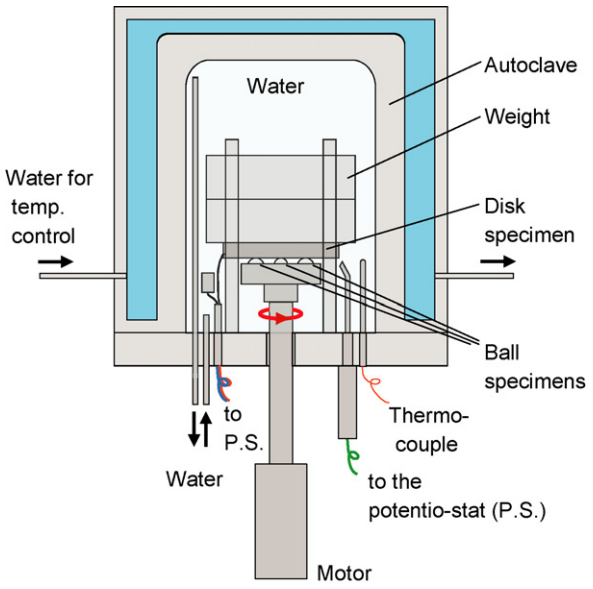

Fig. 1. Schematic diagram of the tribotester for high temperature, high pressure environment in controlled water.

the H900 condition. The diameter of the ball specimen is 9.5 mm. Three ball specimens were used for each single test. Disk specimen is 10 mm in thickness and 50 mm in diameter. DLC and interlayer coatings were deposited using the unbalanced magnetron sputtering system. The substrate surface was sputter-cleaned with Ar ion prior to deposition. Cr interlayer with about 50 nm in thickness was deposited on the stainless steel surface to improve adhesion. Then, Cr–C compositional gradient layer with approximately 200 nm in thickness was deposited which was followed by deposition of DLC layer with 1 μm in thickness. Mixed gas of 10% CH_4 and 90% Ar was introduced in the deposition chamber to add hydrogen in the DLC coating and its content was determined as 30 at.% using the elastic recoil detection analysis (ERDA). The total pressure during the deposition was 0.6 Pa. Bias voltage of −100 V was supplied on the substrate. The deposition temperature was less than 200 °C. The surface hardness of the ball was HV 500 (4.9 GPa). The nanoindentation hardness of the DLC coating was 16 GPa. The surface roughness of both the disk and ball specimens was 0.03 μm in Ra.

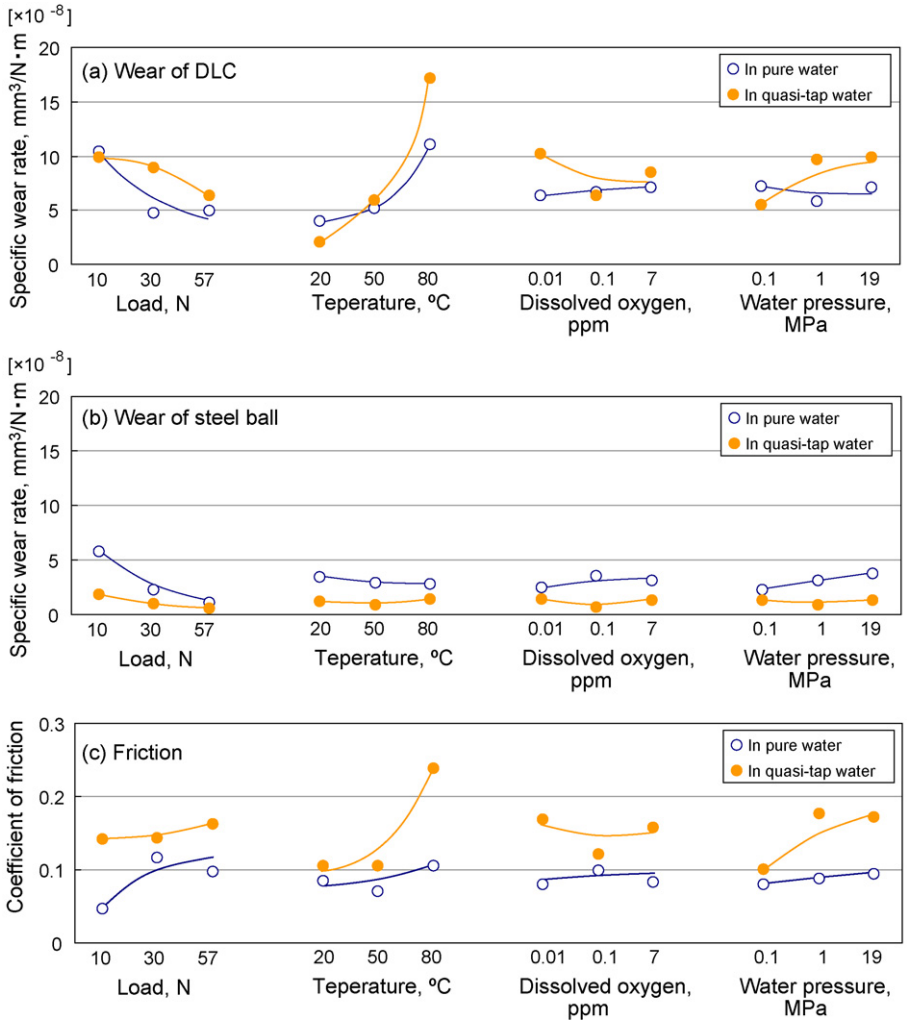

Fig. 2. Extracted effects of environmental factors and load on wear and friction.