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Friction and wear of Cr-doped DLC films under different lubrication conditions☆

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ABSTRACT

In this paper, Cr-doped DLC films with various Cr contents were deposited on stainless steel plates by an ion beam deposition/magnetron sputtering hybrid method and the tribological performance of the samples was evaluated using a ball-on-disk tribometer. It was found that the influence of the Cr content in the Cr-doped DLC films on the friction coefficient when lubricated by PAO, 150SN, PAO + T307, or 150SN + T307 is insignificant while the friction coefficient of the Cr-doped DLC films under PAO + MoDTC or 150SN + MoDTC lubrication can be significantly reduced through the introduction of Cr at an optimum level into DLC films. The wear resistance of the DLC films under PAO, 150SN, PAO + MoDTC, or 150SN + MoDTC lubrication can be improved by the introduction of Cr into DLC films; but Cr doping is unbeneficial to the wear resistance of DLC films lubricated by PAO + T307 or 150SN + T307.

1. Introduction

The improvement of antifriction and antiwear properties of mechanical parts is imperative for the development of modern machines [1]. Diamond-like Carbon (DLC) films are attractive wear resistant films for their high hardness, good wear resistance, and low friction coefficient [2]; but the friction and wear resistance of DLC films are affected by the environments, and their thermal stability is not good enough, hindering the applications of DLC films for severe service conditions [3]. Liquid lubricants can not only abate the disadvantageous effect of environments on the tribological performance of DLC films because they isolate the films from the atmosphere, but also they take away the wear debris and the heat generated during friction so that the demand for high temperature stability is relieved. Therefore, the tribological performance and service life of the DLC-coated mechanical parts can be greatly improved by suitable lubrication [4].

The interaction of lubricant additives with friction surface is closely related to the surface structure and the properties of the friction-pair [5,6], but the tribological performance of DLC films with various doping elements under different lubrication schemes is not clearly understood. In order to fully utilize the excellent tribological performance of DLC films, it is dispensable to study the synergistic effect of the lubricant additives and the DLC films.

Cr-doped DLC films exhibit attractive tribological performance compared with undoped DLC films due to their low stress, high adhesion, and high thermal stability [7,8], and the interaction of the lubricant and the Cr-doped DLC films under boundary lubrication condition has been studied [9,10]. However, the effect of the Cr contents in the DLC films and the lubricant additives on the tribological performance of the DLC-coated samples is not clear.

In this study, Cr-doped DLC films with various Cr contents were first deposited, and then the influence of the Cr content in the DLC films on the friction coefficients and wear rates of the DLC-coated stainless steel samples under various lubrication conditions was studied.

2. Experimental

Cr-doped DLC films were deposited on 316 stainless steel plates in a size of 50 mm × 30 mm × 2 mm, polished to a surface roughness of Ra = 4 nm with a multifunctional coater (AS600DMTG) equipped with rectangular unbalanced magnetron sputtering targets, vacuum cathodic arc sources and linear anodic layer ion sources. Prior to the installation of these samples in the

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deposition system, the substrates were ultrasonically cleaned in the bath solution of water and metal cleaning agent, rinsed in deionized water and ethanol, and then dried in hot air. The sample surface was further etched by argon ions produced by an ion source and Cr ions produced with a vacuum cathodic arc source before the deposition in order to remove the undesirable oxide and contamination on the substrate surface. Then a gradual transition layer was deposited by ion beam assisted magnetron sputtering before depositing Cr-doped DLC films in order to enhance the adhesion between the DLC film and the substrate. During the deposition of the transition layer, the gas composition to the magnetron Cr target with a purity of 99.95% and the ion source was gradually changed from pure argon, to a mixture of argon and nitrogen, then a mixture of argon, nitrogen and methane, and finally a the mixture of argon and methane. After the deposition of the transition layer, Cr-doped DLC films with a thickness of about 1 μm were synthesized by ion beam deposition (the inlet gas into the ion source was the mixture of argon and methane) combined with magnetron sputtering of the Cr target. The operation parameters of the ion source were determined on the basis of the deposition experience of undoped DLC films, and the Cr content in the films was obtained from 0 at% to 23.3 at% by controlling Cr target current. Argon with a purity of 99.999%, nitrogen with a purity of 99.999% and methane with a purity of 99.99% were used in the study.

The surface morphology of the DLC films was observed with scanning electron microscopy (SIRON-200). The chemical bonding status of the DLC films was analyzed using X-ray photoelectron spectroscopy (PHI Quantera), and Mg Kα radiation was used as the exciting X-ray. The sample surface was etched with argon ion for 10 nm in order to avoid the effect of surface contaminants. The hardness and elastic modulus were measured using a nanoindentation tester (MTS XP) with an indentation depth of 1000 nm; the hardness and elastic modulus was determined according to the platform values from 100 nm to 300 nm, and the average value was obtained from five times measurement results.

The friction coefficients and wear rates of the DLC-coated stainless steel samples under different lubrication conditions were evaluated using a ball-on-disk tribometer (MS-T3000). The counterpart was a Si_3N_4 ball of 4 mm in diameter. The DLC-coated stainless steel plate was fixed on a rotary sample stage with a rotation rate of 400 rpm and the diameter of the wear trace was 8 mm. The load was 9.80 N. Polyalphaolefin synthetic oil (PAO-4) and paraffin base mineral oil (150SN) were chosen as the base lubricant oil. The kinematic viscosity at 40 °C of PAO-4 and 150SN is 16.68 mm^2/s and 28–32 mm^2/s, respectively. The viscosity index of PAO-4 and 150SN is 124 and 98, respectively. A friction modifier additive of molybdenum dithiocarbamate (MoDTC) and an extreme pressure antiwear additive of amine sulfuric-phosphate diester (T307) were added as the lubricant additives into the base lubricant oil with a concentration of 1% in weight. The average value was obtained from three times result.

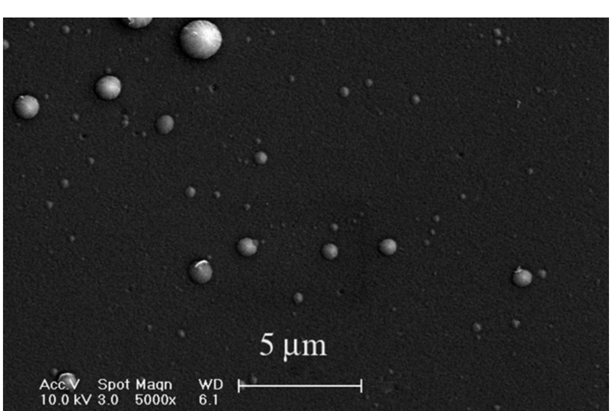

Fig. 1. Surface morphology of Cr-doped DLC films.

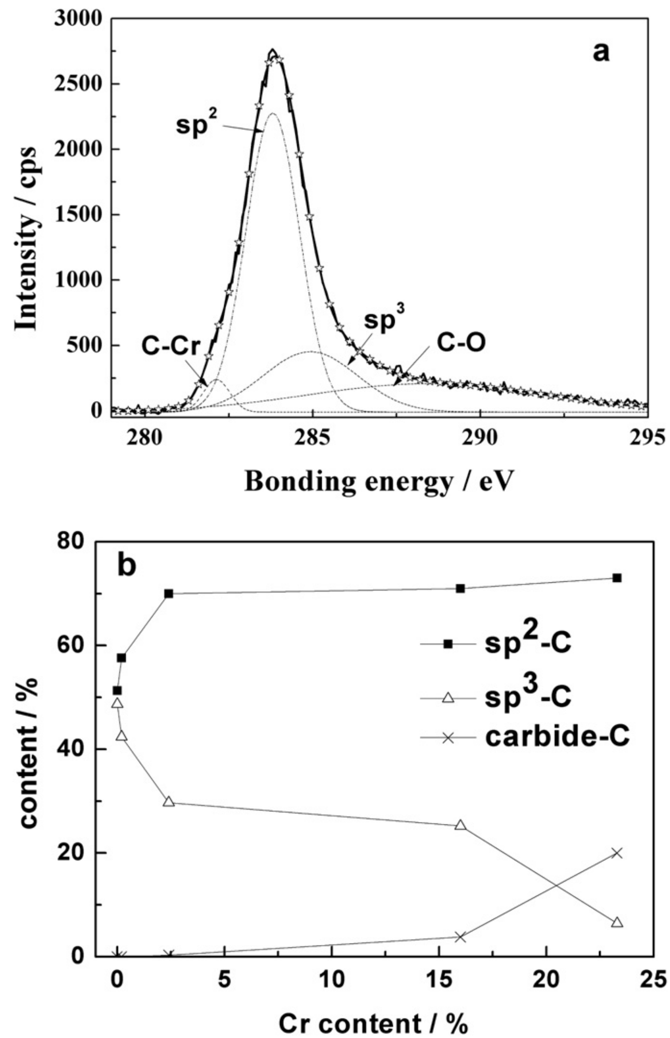

Fig. 2. XPS analysis of Cr-doped DLC films: (a) C1s spectrum of DLC films containing 16 at% Cr, (b) content of carbon atoms with different chemical bonding status as a function of Cr content.

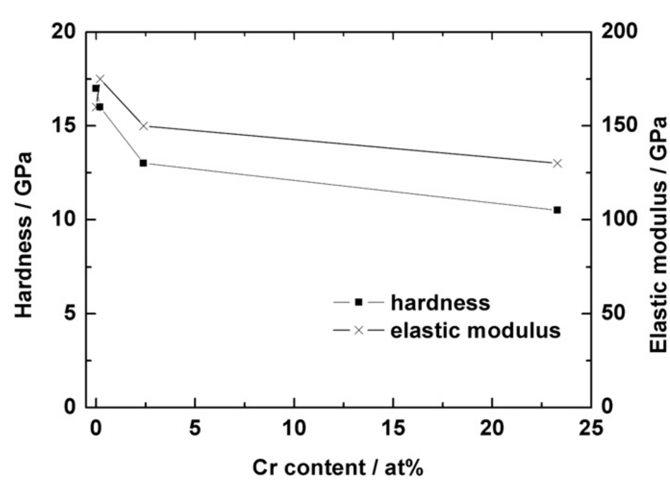

Fig. 3. Hardness and elastic modulus of DLC films as a function of Cr content.