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Tribological Properties of High Hardness ta-CNx Coatings Deposited by Filtered Arc Deposition with Block-on-Ring Tribotester

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Abstract

Low friction and high wear resistance are strongly needed desired in boundary lubrication condition for industrial usage. Carbon nitride (CNx) coating is one of the promising materials, but the hardness of conventional CNx coating was only 10 GPa of nanoindentation hardness. In order to coat high hardness ta-CNx, we developed a dynamic mixing deposition method combining the filtered arc deposition system and nitrogen ion beam source. Nitrogen content was controlled by the nitrogen partial pressure in the deposition. Nanoindentation result gave the hardness of ta-CNx from 75 to 70 GPa, under the nitrogen content from 5 to 8 at.%. In order to clarify the tribological performance of ta-CNx coatings under the boundary lubrication, block on ring friction test was carried out. As a result, this new ta-CNx showed much higher wear resistance compared to the former soft CNx and hard ta-C coatings under PAO lubrication for the block-on-ring tribotester.

Keywords: ta-C, ta-CNx, filtered arc deposition, friction, wear

1 Introduction

There are many researches which focus on the use of Diamond-like Carbon (DLC) coatings under boundary lubricated contacts to reduce the friction loss and to protect the mechanical components (Grill, 1999, Vengudusamy et al., 2012). Carbon nitride (CNx) coating is an unique low friction material, which realizes ultra-low friction coefficient of 0.01 in nitrogen atmosphere (Umehara et al., 1998, Umehara et al., 2000, Tokoroyama et al., 2000). It was reported that Si_3N_4/CNx or CNx/CNx provided friction coefficients of 0.01-0.001 in dry nitrogen gas (Adachi et al., 2005) and in water (Zhou et al., 2007). Also the influence of UV irradiation in low frictional performance of CN_x coatings was shown (Tokoroyama et al., 2012) and it is expected to be applied on sliding parts of machines.

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However, there is a problem of CNx coatings that hardness is relatively low. In normal coating methods, the hardness of CNx is lower than that of DLC coatings. For example, the hardness of CNx shows 3.9-21.6 GPa by Chemical vapor deposition (CVD) [9], 4-17Pa by magnetron sputtering (MS) and 10-20 GPa when deposited by Ion Beam Assisted Electric Beam Deposition (IBA-EBD) (Tokoroyama et al., 2011). Doping a-C films with nitrogen has the added advantage due to reduction of residual stress in coatings, but decreased the hardness (Hammer et al., 1997).

Therefore, it is necessary to improve the mechanical properties of CNx to increase the durability of CNx coatings. Based on this motivation, doping nitrogen into tetrahedral amorphous carbon (ta-C) was considered in this study. It is known that ta-C is made from ion or plasma beams with a high ion fraction and a narrowly defined ion energy. Filtered Arc Deposition (FAD) is widely used for ta-C deposition because it can supply high fraction carbon ions with certain energy (Takikawa et al., 2003). Their ta-C showed more than 70 GPa in hardness.

Therefore, we proposed a new deposition method for ta-CNx with Nitrogen ion beam assisted filtered arc deposition to deposit hard ta-CNx. Also we investigated the effect of nitrogen on the mechanical properties, the crystal structures, and tribological properties with block-on ring friction tester in oul lubrication by changing the nitrogen content in the CNx coating systematically.

2 Experimental

For the deposition of high hardness tetrahedral amorphous carbon nitride (ta-CNx) coatings, we developed the dynamic mixing deposition method combining the filtered arc deposition system and nitrogen ion beam system (Ion Beam Assisted Filtered Arc Deposition, IBA-FAD) as shown in Fig.1. Carbon ions from a cathodic arc evaporation and nitrogen ions which were provided by ion source were simultaneously deposited on the substrate. Nitrogen content in the ta-CNx coatings was controlled by nitrogen partial pressure from 5.2×10^{-2} to 3.94×10^{-1} Pa. Nitrogen content in ta-CNx was measured by XPS. For the measurement of hardness of the coatings, nanoindenter was used. To clarify the effect of nitrogen adding on bonding structure of ta-CNx coatings, Raman spectroscopy was used. Thickness of ta-C was measured by the measurement of step height of coating after masking method with AFM.

In order to clarify the tribological performance of ta-CNx coatings under the boundary oil lubrication, block on ring friction test was carried out. AISI440C block specimen was coated with ta-CNx coatings which were deposited in the same batch. Figure 2 shows the schematics of block-on-ring friction tester. Normal load was applied by a dead weight system. Friction force was measured by strain gauges system. The part of SAE4620 ring specimen was dipped in oil bath. Sliding conditions are shown in Table 2. The lubricating oil used in the test was a base oil poly alpha olefin (PAO) and oil temperature was set to be room temperature.