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Case study

The tribological properties of Zr-C:H coatings deposited on AISI M2 substrate

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Abstract

Zr-C:$H_{x\%}$ coatings are deposited on AISI M2 steel disks using an unbalanced magnetron (UBM) sputtering method with a single zirconium metal target, three graphite targets and various CH_4 reactive gas flow rates in the range of 0–5 sccm. The results show that the CH_4 flow rate has a significant effect on the microstructural, adhesion and tribological properties of the coatings. Specifically, the microstructure changes from a columnar form to a featureless morphology as the CH_4 flow rate increases. Furthermore, an increasing CH_4 flow rate increases the coating hardness and results in a lower wear depth and friction coefficient under sliding with an AISI 1045 steel cylinder.

Keywords: Zr-C:$H_{x\%}$ coating; Tribological properties; Hydrogen content

1. Introduction

Diamond-like carbon (DLC) coatings possess excellent mechanical and tribological properties, including a low friction coefficient and a high wear resistance [1–6]. However, such coatings are characterized by high residual stress, and hence their practical applications are somewhat limited. Previous researchers have attempted to enhance the adhesion properties of DLC coatings by doping the coating with various metals [7–11]. Broadly speaking, DLC coatings can be classified as either hydrogenated diamond-like carbon coatings (amorphous hydrogenated carbon coatings, i.e. a-C:H) or hydrogen-free diamond-like carbon coatings (tetrahedral amorphous hydrogen-free carbon coatings, i.e. ta-C). In general, the wear resistance properties of ta-C coatings are better than those of a-C:H coatings. However, a-C:H coatings generally have a lower friction coefficient than ta-C coatings [12]. It has been reported that the hydrogen content of DLC films has a fundamental effect on their frictional behavior [13]. DLC coatings can be prepared using a variety of techniques, including laser processing [11], magnetron sputtering [14], unbalanced magnetron (UBM) sputtering [15], radio frequency (RF) and plasma enhanced chemical vapor deposition (PECVD) [16], electron cyclotron resonance (ECR)[17], and so forth. In these manufacturing methods, the carbon source of ta-C coatings is generally provided by a single graphite target, while that of a-C:H coatings is usually provided by the reactive gas.

In the present study, Zr-C:$H_{x\%}$ coatings are deposited on AISI M2 steel disks using a UBM sputtering method with a zirconium (Zr) metal target, three graphite (C) targets, and various methane (CH_4) gas flow rates ranging from 0 sccm (i.e. no reactive gas) to 5 sccm. The mechanical, adhesive and tribological properties of the resulting Zr-C:$H_{x\%}$ coatings are systematically analyzed and discussed.

2. Experiment

2.1. Coating preparation

The Zr-C:$H_{x\%}$ coatings were deposited on the AISI M2 steel disks using the UBM sputtering method (UDP-450, Teer Coating, UK) with one Zr target, three C targets and CH_4 reactive gas. During the deposition process, the substrate was maintained at a temperature of 185–200 °C (as measured by a thermocouple positioned in the vacuum chamber) and was subjected to a pulse bias voltage of −40 V. Prior to the deposition process, the surfaces of all the substrates were polished to a roughness of $Ra \sim 0.008$ μm and were then processed via argon ion bom-

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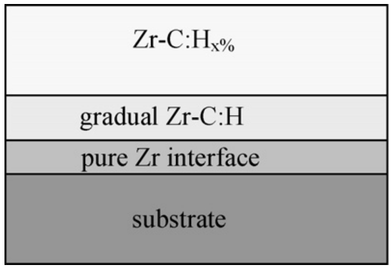

Fig. 1. Schematic diagram of Zr-C:$H_{x\%}$ coating.

Table 1
Deposition parameters for Zr-C:$H_{x\%}$ coatings

Parameters	Zr-C:$H_{x\%}$ coatings
Reaction gas	CH_4
Chamber pressure (Torr)	5×10^{-5}
Working pressure (Torr)	1.5×10^{-3}
Substrate bias voltage (V)	−40 (DC pulse, duty cycle 50%)
Graphite target current (A)	2.0 (DC, 1.28 kW)
Zr target current (A)	0.4 (0.7 for pure Zr layer as interface and 0.5 for gradual layer, 68 W)
Substrate temperature (°C)	185–200

bardment for 10 min at a bias voltage of −350 V. A pure Zr layer was then deposited on the surface of each substrate to form an interfacial layer. Finally, DLC coatings were deposited on the substrates using the UBM deposition method (Fig. 1). To investigate the effect of different mixed carbon sources on the coating properties, the coatings were deposited using various CH_4 reactive gas flow rates in the range of 0–5 sccm. The deposition parameters are summarized in Table 1.

2.2. Observation and analysis equipment

The microstructural characteristics of the various Zr-C:$H_{x\%}$ coatings were examined using an X-ray diffractometer with Cu Kα radiation. The diffractometer was operated at 40 kV and 100 mA, and the scanning operation was performed using the conventional θ–2θ method. The cross-sectional thickness and profile images of the coatings were acquired using a scanning electron microscope (SEM). The hardness of each coating was evaluated using a nanoindentation tester (TriboScope, Hysitron Inc., USA) with a force at final contact of 5 mN. The compositional content of the coatings was analyzed using glow discharge spectrometry (GDS). The adhesion characteristics of the coatings were investigated using a standard Rockwell-C hardness tester with an applied load of 150 kgf. In accordance with the method proposed in ref. [18], the adhesion properties of the thin coatings were gauged by examining the appearance of the radial and lateral cracks in the coating around the indentation. In ref. [18], the authors identified five distinct cracking and flaking failure modes for thin coatings, as shown in Fig. 2. It can be seen that failure mode A has only radial cracks around the indentation. This failure mode is generally indicative of a thin coating with good adhesion characteristics. However, thin coatings with poor adhesion properties typically fail with a Mode E failure, i.e. a large annular area of the coating flakes off around the indentation.

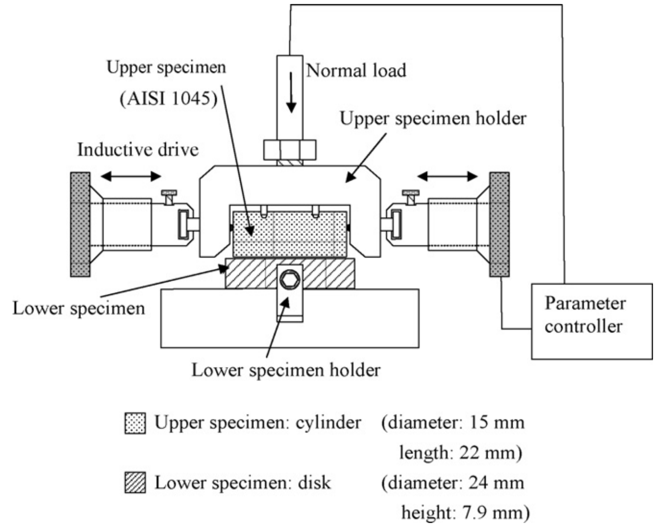

Fig. 3. Schematic illustration of SRV wear test machine.

2.3. Wear tests

The wear characteristics of the coatings were quantified using an SRV reciprocating sliding wear tester (Schwingung Reibung and Verschleiss Tester, Optimal, Germany). The experimental setup is illustrated schematically in Fig. 3. As shown, the test apparatus consists mainly of a stationary lower specimen supporter and a reciprocating upper specimen holder. In the current wear tests, the upper specimen was an AISI 1045 steel cylinder (Ø15 mm × 22 mm) with a hardness of HRB 104 (Rockwell-B scale), while the lower specimen was the variously-coated M2 steel disks. The wear tests were performed using an applied load of 100 N, a stroke length of 0.2 mm, and a reciprocating frequency of 25 Hz. Each test was performed for a total

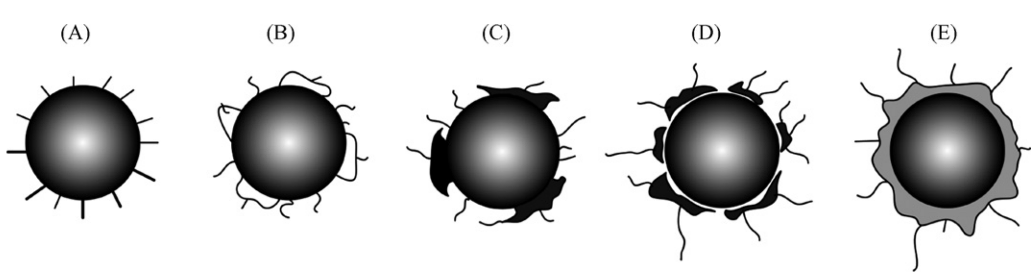

Fig. 2. Typical failure modes of thin coatings in Rockwell-C indentation test.