The tribological properties of the Zr/a-C:Zr/DLC-x coatings under ball-on-disk wear mode

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1. Introduction

DLC coatings have been produced by many deposition techniques and in order to overcome the problem of low adhesion on metallic and ceramic substrates, different coating concepts have been proposed by many research groups [1-4]. The studies have shown that the adhesion properties of DLC coatings can be improved via a design of a tailored interface in the form of a gradient interlayer or a multilayer coating between the substrate material and the carbon film [5, 6]. Another used method is the addition of various metals [7-11]. As a result, doped metal DLC coatings can be improved via a design of a tailored interface in the form of a gradient interlayer Zr/a-C:Zr. However, the effects on the coating properties and tribological behaviour was discussed based on hardness (H), elastic modulus (E), adhesion property, initial Hertzian pressure and transferred layer on contact surfaces of wear pairs. The tribological properties of the resulting DLC coatings are systematically analyzed and discussed.

2. Experimental details

2.1. Coating deposition

The coatings were deposited on AISI M2 steel disks using a CFUBM sputtering system (UDP-450, Teer Coating, UK) with a single zirconium (Zr) target, three graphite targets, and C2H2 and CH4 reaction gases. DLC-x topcoats were deposited on a c-Zr layers, which operated pulse frequency in the range 30 kHz to 110 kHz (the x in the term DLC-x is the power frequencies in the deposition process). The study investigates the tribological properties of the Zr/a-C:Zr/DLC-x coatings under ball-on-disk point contact wear mode using an oscillation friction and wear tester. The mechanical, microstructure and tribological properties of DLC coatings have been produced by many deposition techniques and in order to overcome problems of low adhesion on metallic and ceramic substrates, different coating concepts have been proposed by many research groups [1-4]. The studies have shown that the adhesion properties of DLC coatings can be improved via a design of a tailored interface in the form of a gradient interlayer or a multilayer coating between the substrate material and the carbon film [5, 6]. Another used method is the addition of various metals [7-11]. As a result, doped metal DLC coatings are now finding increasing use for many industrial applications. In this study of amorphous hydrogenated diamond-like carbon coatings (DLC-x) with doped Zr metal deposited onto gradient interlayer Zr/a-C:Zr. The experiments were performed using a CFUBM sputtering system with pulsed-DC power frequencies in the range 30 kHz to 110 kHz. The mechanical, microstructure and tribological properties of the resulting DLC coatings are systematically analyzed and discussed.

2.2. Wear test

The tribological properties of the DLC-x coatings were evaluated using a SRB (Schwingung Riefungs Vieleckhle) oscillation friction and wear tester (Optimol, Germany). The tester comprised a lower specimen supporter and an upper specimen holder. In the present tests, the upper specimen was Al2O3 balls (diameter 10 mm), while the lower specimens were the coated AISI M2 disks (diameter 24 mm, thick 7.9 mm). Wear testing was performed using a constant 1 mm stroke, a 10 N normal load, a 24 minutes test duration and a 500 Hz oscillation frequency. Following each test, the maximum depth of the wear scar on the coated disk was measured using an optical profilometer (LBB, BMT, Germany). Each coating was tested twice, with three separate depth measurements taken on each occasion. The six measurements were then averaged to obtain an overall wear depth value for the coating.

3. Results and discussions

The hardness (H) and elastic modulus (E) values of DLC-x coatings as a function of the pulsed-DC frequency are shown in Table 1. The coating hardness increases from 28 GPa to 42 GPa as the frequency is increased from 30 kHz to 70 kHz, but then reduces to 26 GPa as the frequency is further increased to 110 kHz. The reduction in hardness in the coatings deposited with lower or higher pulsed-DC frequency that it suggests a progressive graphitization. The elastic modulus of DLC coating was measured to be in the range of 219-358 GPa. Consequently, the highest values of coating hardness and elastic modulus were obtained from the Zr-C:H coatings deposited at 70 kHz, and the lowest values of coating hardness and elastic modulus were obtained from the DLC-x coatings deposited at 110 kHz, respectively. In other words, the Zr-C:H-70 coating possesses the highest hardness and elastic modulus (i.e.42 GPa and 358 GPa, respectively), while the Zr-C:H-110 coating possesses the lowest hardness and elastic modulus (i.e.26 GPa and 219 GPa, respectively).

4. Conclusions

The experimental results support the following major conclusions:

- The Zr-C:H-110 and Zr-C:H-70 coatings possess the best coating adhesion and the highest hardness, respectively. The Zr-C:H-110 coating with the lowest initial Hertzian pressure, the lowest friction coefficient and a stable lubricant transferred layer on the Al2O3 ball, yields the excellent tribological properties as sliding against an uncoated substrate.

Keywords: Pulsed-DC, Tribological behaviour, Hertzian pressure

Abstract. In theory, diamond-like carbon coatings (DLC) possess high fatigue life, high hardness, high chemical inertness, low friction and high wear resistance. Those properties of DLC coatings depend on the deposition method and applied conditions. However, the effects on the coating properties of the pulsed-DC power frequency used in the deposition process have received comparatively little attention. Accordingly, in this study the gradient coating design of amorphous hydrogenated diamond-like carbon with doped Zr metal (DLC-x) deposited onto the interlayer Zr/a-C:Zr, and then Zr/a-C:Zr/DLC-x coatings are deposited on substrate AISI M2 steel disks using a closed field unbalanced magnetron (CFUBM) sputtering system with pulsed-DC power frequencies in the range 30 kHz to 110 kHz (the x in the term DLC-x is the power frequencies in the deposition process). The study investigates the tribological properties of the Zr/a-C:Zr/DLC-x coatings under ball-on-disk point contact wear mode using an oscillation friction and wear tester. The tribological behaviour was discussed based on hardness (H), elastic modulus (E), adhesion property, initial Hertzian pressure and transferred layer on contact surfaces of wear pairs. The experimental results display the DLC-x coating with the good adhesion property, the lowest initial Hertzian pressure and the lowest friction coefficient possesses excellent wear resistance.

Table 1. Coating mechanical properties (DLC-x: elastic modulus (E))

<table>
<thead>
<tr>
<th>Coating</th>
<th>Hardness (GPa)</th>
<th>Elastic modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DLC-50</td>
<td>28-35</td>
<td>358-39</td>
</tr>
<tr>
<td>DLC-50</td>
<td>39-35</td>
<td>358</td>
</tr>
<tr>
<td>DLC-70</td>
<td>42-35</td>
<td>358</td>
</tr>
<tr>
<td>DLC-90</td>
<td>37-34</td>
<td>303</td>
</tr>
<tr>
<td>DLC-110</td>
<td>26-31</td>
<td>219</td>
</tr>
</tbody>
</table>

Fig. 1. Durability lifetime of various DLC-x coatings, and wear depth for sliding against Al2O3 ball for 24 minutes of testing.

Fig. 2. Friction coefficient of DLC-x coatings for sliding against Al2O3 ball for 24 minutes of testing.

Fig. 3. Typical wear surfaces of DLC-x coatings, and wear depth for sliding against Al2O3 ball for 24 minutes of testing.