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Textured hybrid nanocomposite coatings for surface wear protection of sports equipment

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ABSTRACT

Surface treatment and coating are widely used to enhance the performance and wear life of industrial components. However, the development of high performance wear protective coatings for sports equipment is still a challenge, as the coatings are subjected to harsh conditions that require good coating adhesion and wear resistance. This work aims to develop a textured CrAlSiN plus carbon nanocomposite coating to improve the wear performance.

Si wafer and stainless steel substrates were textured by photolithography and wet chemical etching. CrAlSiN plus carbon nanocomposite coatings were developed using a plasma enhanced physical vapour deposition (PEPVD) system. It was found that the textured nanocomposite coating demonstrated substantially improved adhesion strength, long-standing low friction coefficient and reduced volume loss rate, giving rise to significantly improved wear resistance.

1. Introduction

There is an increasing demand for wear resistant coatings with good adhesion and low friction coefficient, particularly for sports equipment that are constantly subject to impacts and wear, for example, golf clubs and air rifle barrels. Nitride based nanocomposite coatings, with nanometre sized grains embedded in an amorphous matrix [1], are known to have superior hardness and fracture toughness [2–4], making them strong candidates for wear protection applications. However, these hard coatings often have relatively high friction coefficient [5] which compromises the wear performance, especially in three-body wear conditions where the hard material scrapped off from the coating becomes the abrasive particle [6]. To address this issue, hybrid coatings consisting of a thin lubricating layer on top of a hard nitride layer have been developed with the aim of reducing the friction coefficient without significantly reducing the coating's hardness [7,8]. However, the performance of such coating is not satisfactory, as the top layer is not durable enough to provide long term lubrication effects, and that the rapid depletion of the lubricating layer leads to a steep increase in friction coefficient and wear rate.

Surface texturing was reported to demonstrate unique benefits for surface protection, especially the ability to reduce the friction coefficient [9,10]. Previous studies on sliding contacts have also shown that microtextures on the surface can serve as reservoirs to store the lubricant and subsequently become a secondary lubricant source [11], and that the surface textures can help to trap wear debris, reducing the abrasive wear between the contact surface [12,13]. Such surface patterns could be created by laser texturing [14], especially on metal surfaces. However, the process is usually associated with heat affected zones around the pattern, causing changes in both the material properties and the surface profile, and therefore limiting the applications of the method. Alternatively, photolithography could be used, which is suitable for fast surface patterning on a large range of material and surface geometries.

The concept of surface texturing could be beneficial to the design of hybrid coatings, especially in terms of conserving the materials from the top lubricating layer and extending the lubrication effects. Fig. 1 shows the schematics of a hybrid coating consisting of a hard bottom layer and a lubricating top layer deposited on textured substrate, (a) & (b), and in sliding contact with a ceramic ball. As the top layer is softer, it is more vulnerable to the abrasive wear, Fig. 1 (c). However, the lubricious material from the top layer will not be completely depleted by the sliding wear, as they could be trapped inside the surface dimples and continue to serve as dry lubricant for the surface contact, Fig. 1 (d). The shape and distribution of the textures may also affect the coating properties, especially the anisotropy of the surface. So to preserve the isotropic nature of the coating, circular patterns uniformly distributed across the surface should be used for the texturing. Based on this concept, textured hybrid coatings consisting of a CrAlSiN nanocomposite base layer with superior hardness and fracture toughness and a top carbon composite layer with dry lubrication properties [15] were developed in this paper, and we aim to investigate the effect of substrate texturing on the wear performance of such hybrid coatings.

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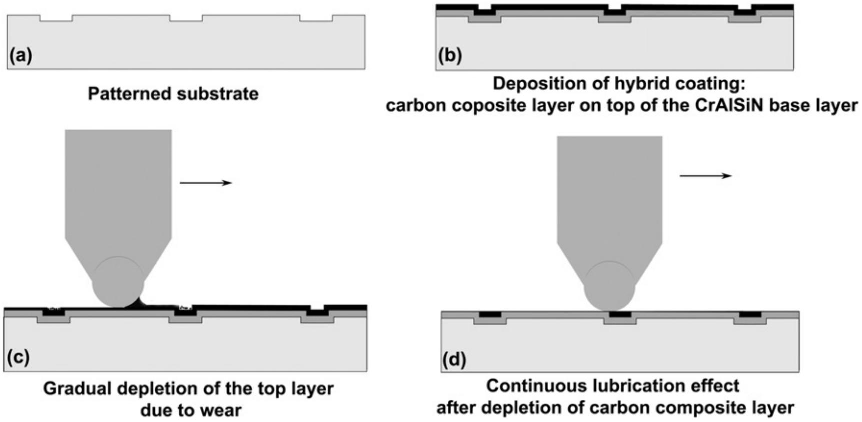

Fig. 1. Design concept of the textured hybrid nanocomposite coating.

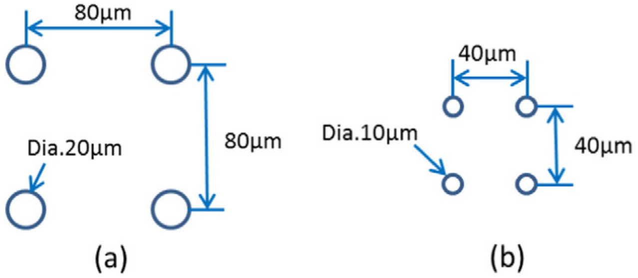

Fig. 2. Schematic of the texture patterns.

2. Experimental

2.1. Substrate texturing

Si (100) wafers with a 100 nm SiO_2 layer and stainless steel coupons 30 mm in diameter were used as the substrates. The Si wafers were textured with the pattern shown in Fig. 2 (a) using photolithography and buffered HF solution. The Si bulk was further etched in KOH (50 wt%) at 80 °C to depths of 6 μm and 2.5 μm respectively.

Mirror polished stainless steel plates were also etched with two types of patterns, as shown in Fig. 2 (a) & (b), using standard photolithography techniques and CE-100 ferric chloride etchant. The etching was conducted at 50 °C for 3 min to obtain an average depth of 2.8 μm.

2.2. Coating deposition

Hybrid coatings consisting of a CrAlSiN nanocomposite base layer and a lubricating carbon composite top layer were deposited using a plasma enhanced physical vapour deposition (PEPVD) system with two Cr targets, two C targets and two AlSi targets installed symmetrically around the cylindrical chamber. Prior to the deposition, an intensive plasma cleaning process was conducted for 20 min to remove possible residual contaminants and native surface oxide layer on the substrates. The base CrAlSiN nanocomposite layer was deposited by co-sputtering the Cr and AlSi targets in an Ar and N_2 atmosphere, while the top carbon composite layer was formed by sputtering the C targets in an Ar and C_2H_2 atmosphere. A small amount of Cr was also doped into the carbon composite coating to reduce the internal stress and enhance the coating adhesion [16]. Throughout the deposition process, the substrates were biased with pulsed DC power at −60 V and the substrate holder rotates at 6 rpm around the chamber to ensure the homogeneity of the coatings. For fair comparison, non-textured substrates were also coated in the same batch with the textured ones.

2.3. Coating characterization

The coating microstructure and surface features were characterized by scanning electron microscopy (SEM) and 3D surface profilometer. Coating hardness and Young modulus were measured by nanoindentation (NanoTest, MicromMaterials, UK) with a diamond Berkovich indenter, where the load–displacement data were analysed using the Oliver–Pharr method [17]. The maximum indentation depth was set to be less than one tenth of the coating thickness [18], such that the substrate effects were negligible. The coatings' resistance to cracking was characterized using Rockwell C indentation at a normal load of 150 kg.

The wear resistance of the coatings was characterized using a tribometer (CERT-UMT) with a 9.53 mm diameter alumina ball. The wear tests were carried out under ambient condition without lubricant and in a linear reciprocating mode with a stroke length of 6 mm and frequency of 4.75 Hz. The reciprocating wear tests were conducted at

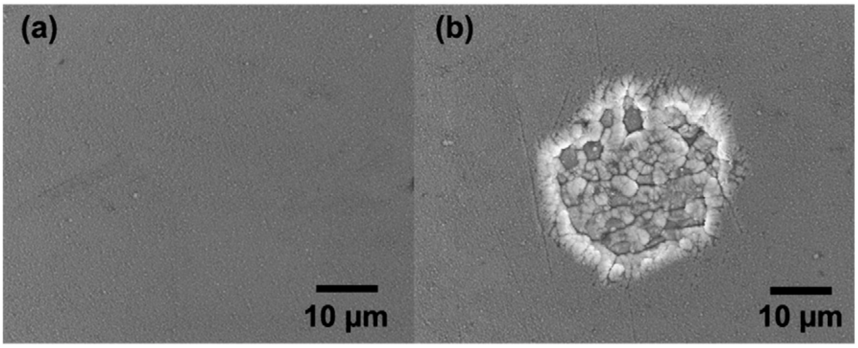

Fig. 3. Surface SEM images of (a) non-textured and (b) textured coatings.