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Tribological behaviours of patterned PVD TiN spot coatings on M2 steel coated with different bias voltages

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Abstract

Experiments were performed to investigate systematically the tribological behaviours of in-lined and staggered spot-island PVD TiN patterns on M2 steel discs sliding with ASSAB 17 tool steel pins. Testing results on disc specimens with full PVD TiN coating and with the two types of PVD TiN spot-island patterns coated under three bias voltages (i.e. −30, −90 and −180 V) were presented. Results revealed that both in-lined and staggered patterned coatings possessed relatively better wear behaviours (with in-lined patterned coating being the most superior) than the fully coated discs. Mechanisms for such superiority were discussed in this paper.
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Keywords: PVD TiN patterned coating; Substrate bias voltage; Friction; Wear

1. Introduction

Surface texture significantly affects the wear and friction characteristics between two mating surfaces under sliding condition. Studies [1–10] showed that the proper orientation of patterns like (i) micro-irregularities and/or (ii) cavities reduced wear since they trap wear particles from the sliding surface [1–3], which recursively (a) alleviated the gross macroscopic and microscopic ploughing and delamination to generate wear particles and (b) prevented the agglomeration of wear particle [5,6]. As a result, the values of friction and wear for sliding couples with patterned surfaces were lower than those unpatterned counterparts. Under lubrication condition, different directional patterns on substrate material have different load-bearing capacities under mixed lubricated conditions because of their different hydrodynamic lubrication effects between the two parallel sliding surfaces. The length-to-width aspect ratio γ (generally known as orientation index) of islandic patterns affects the load-bearing capacity and tribological behaviour. Tests under lubrication conditions [7,8] suggested that transverse island surface pattern with $\gamma < 1$ generally enhances load-bearing capacity and produces low friction. Studies [9,10] also showed that different micro-irregularities and cavities on two sliding surfaces yielded different hydrodynamic lubrication conditions and tribological performances. Generally, repetitive production of tribological patterns on substrate material by machining is slow and costly. Since surface coating and treatment techniques are relatively easier to control for modifying the surface textures and properties of substrates, they thus become effective technologies for improving tribological behaviours of mechanical engineering components [11].

TiN coatings produced by physical vapour deposition (PVD) TiN coating technique are widely used in improving the tribological properties of high-speed steel cutting tools [11,12] and some mechanical components [13,14]. Research into friction and wear characteristics and failure mechanisms of TiN coatings [15–18] have shown that PVD TiN coating minimizes wear loss and diminishes failure of components.

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TiN coating frequently offers excellent corrosion protection and surface finish, and high resistance to wear with low coefficient of friction [19–22]. Its coating temperature is normally between 450 and 500 °C, which is relatively low to distort steel substrate and thus likely to preserve the mechanical properties of the coated components.

Furthermore, sliding tests of AISI M2 high-speed tool steel islandic spots patterned on the same substrate discs (with spots being arranged in in-lined (IN) and staggered (ST) pattern, respectively, on individual discs) against ASSAB 17 tool steel flat pin specimens in lubrication condition showed obvious improvement in tribological characteristics when compared with their unpatterned counterparts [23]. It was envisaged that the replacement of base-material patterns by the spotted PVD TiN coating might integrate the advantageous tribological performances of both hydrodynamics and coatings under wet lubrication sliding conditions. Preliminary study on tribological behaviours of some PVD TiN patterns on M2 steel was thus conducted [23]. Both microstructure and hardness of PVD TiN coating changed with substrate bias voltage in the PVD process [24,25]. Increase in substrate bias voltage usually increases thermal energy for columnar grains formation in the coating [26] and for improving the interfacial adhesion between coating materials and substrate [27,28]. Qualitative evaluation of irregular PVD TiN patterned coating on substrate is difficult without the understanding of the role of substrate bias voltage in the tribological performance of coating specimens. This research work studied the variation of tribological characteristics of PVD TiN coating patterns coated with different substrate bias voltages by an arc ion plating (AIP) process.

2. Methodology

All specimens were firstly soap-cleaned, then ultrasonically cleaned in an acetone bath and carefully blow-dried before relevant measurement or coating or test was performed.

2.1. Test specimens and coating preparation

In this study, pin specimens (6 mm diameter × 63 mm length) were made of ASSAB 17 tool steel with hardness, measured by Hysitron's Triboscope nano-indenter, of 15 GPa. Their surface was firstly machined and ground to 0.85 μm Ra, and then lapped by an Engis Hyprez (model 15LC230) lapping system to a parallelism and flatness (as measured by 3D Form Talysurf Stylus Profilometer) at about 0.01 μm. The full or patterned PVD TiN coating discs were prepared from the AISI M2 high-speed tool steel flat disc specimens (74 mm diameter × 5.4 mm thickness) having hardness of 5.6 GPa. Individual disc specimens were ground to a final average surface finish of 0.08 ± 0.01 μm Ra before deposited with either full or patterned TiN coating by a multi-arc ion-plating machine with the coating deposition parameters as tabulated in Table 1 for depositing coating thickness in range of 2–3 μm, as measured by the cross-sectional SEM micrographs.

To coat the spot-patterned coatings by arc ion plating (AIP) process, it was almost impossible to sputter the coating spots without masking off the uncoated regions on the individual discs from the stream of PVD Ti droplets. It would also be hard to bombard Ti stream onto a coating substrate, with reasonable adhesion strength, through very small holes on a masking shield. In view that (i) the study was to investigate preliminarily the tribological characteristics of spot PVD TiN patterned coatings, (ii) the size and arrangement of the holes had to be easy and relatively cheap to produce, and yet to provide coating with relatively good adhesion strength, and (iii) the preliminary sliding tests of islandic AISI M2 tool steel spots arranged in IN and ST, respectively, on the same substrate discs in Ref. [23] gave better tribological behaviours than their unpatterned counterparts, the arrangement of the corresponding IN and ST PVD TiN spot-patterned coatings was thus following those AISI M2 tool steel spots as preliminarily studied, and their coated discs are as shown in Fig. 2.

For preparing in-lined (IN) and staggered (ST) patterned coating, respectively, on the disc specimens, AISI M2 high-speed steel masking shields (2 mm thick × 78 mm diameter) as shown in Fig. 1 were specifically made to mask off the PVD Ti stream. The thickness of masking shields was so selected so as to optimize the stiffness of the shields and to minimize the blockage to their stream of Ti droplets [23]. The holes corresponding to the position of IN or ST patterned coating on the shields were drilled and deburred with linear accuracy of ±0.005 mm between the centres of neighbouring holes and angular accuracy of ±0.01° between the neighbouring radial central-lines along individual sets of circular drilled holes. The surface flatness of the shields was ground and lapped to within ±0.005 mm so as to prevent TiN coating squeezing into the mating edge of the holes. A locking "hooked" flange was designed around the peripheral rim of the shields so as to prevent relative shifting of the shield-disc assembly and to mask the edge rim of the discs from coating.

Individual assemblies were placed, as cathode, at a distance of 125 mm away from the titanium (Ti) anode in a 2×10^{-5} mbar coating chamber of a multi-arc ion-plating

Table 1
Setting of coating deposition parameters in multi-arc ion-plating machine

Coating deposition parameters	
Substrate bias voltages (V)	−30, −90, −180
Arc current (A)	60
Deposition temperature (°C)	400 to 450
Chamber pressure (or partial pressure of N_2) (mbar)	10^{-2}
Deposition rate (μm/min)	0.05
Target-substrate distance (mm)	125
Coating thickness (μm)	2–3

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