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Adhesion and multipass scratch characterization of Ti:Ta-DLC composite coatings

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ABSTRACT

DLC (diamond like carbon) is one of the most studied coatings due to its excellent mechanical and tribological properties, desirable chemical inertness and high corrosion resistance hence it has been widely used in industrial applications for a long time. However, low adhesion and low fatigue resistance are disadvantages of this coating. In this study, we deposited Ti:Ta doped DLC graded-composite coatings on Ti6Al4V and M2 substrates and adhesion and multipass scratch behaviors were characterized. SEM, EDAX and XRD were used to determine the structural properties. Adhesion and fatigue-like behaviors were obtained by scratch tests. The results showed that the critical loads and fatigue resistance of the coatings were affected by the target currents and the hardness of the coatings and substrate.

1. Introduction

Carbon is the most abundant element on the planet and has large number of allotropes hence it is one of the most important elements in the periodic table. Diamond-like carbon (DLC) is an allotropic form of the carbon that the structure consists of sp^3, sp^2 and sp. bonds. DLC coatings have high hardness, low coefficient of friction, chemical inertness and semiconducting properties. DLC coatings have wide application areas from tribological applications to biomedical and optical applications. DLC coatings can be classified in many ways. According to the presence of an additional element in the structure, the coatings are called doped or undoped. Doped DLC can be divided into two subclasses as metal depod (Ti,W,Mo,Cr etc.) and nonmetallic doped (Si, F, N,B etc.). Undoped DLC coatings can be classified according to the presence of hydrogen. It exhibits high friction in the absence of hydrogen atoms in the DLC coating cause of accruing very little movement of the sliding surfaces. The presence of hydrogen in the structure lowers the coefficient of friction.

DLC coatings exhibit good wear resistance and low coefficient of friction but when deposited on metal based substrates, the adhesion of the coatings is not enough for good service life [1,2]. Many studies have been conducted to further improve the mechanical, tribological, adhesion and fatigue properties of the DLC coatings. The metal-doped DLC coating in particular offers high mechanical and tribological properties. The Ti-doped DLC coatings generally show high hardness and wear resistance [3–5]. Fe, Si and N are added to DLC to improve the hardness and structural properties. Bewilogua et al. [6] added Ti, Nb, W and WC into DLC to improve the mechanical and tribological properties. Qiang et al. [7] produced W/Ti doped DLC coatings and improved the hardness and wear resistance of the DLC coatings. Vitu et al. [8] deposited Zr doped DLC and reached a low surface energy and coefficients of friction according to the pure DLC. Along with these studies, many works have been done to improve the adhesion of the DLC coatings deposited on ferritic substrates. Czyzniewski [9] deposited W doped DLC and optimized the adhesion properties. Adding Si containing interlayer between metal substrate and DLC coating helped to improve the adhesion [5,10]. Using Ti and TiN interlayer improves the adhesive bonding and plays an important role as corrosion and crack barrier between the substrate and DLC coating [11–13]. Tantalum and Tantalum nitride were also used in some recent studies to improve mechanical and tribological behaviors of the thin solid films [14,15]. Bernoulli et al. [16] added Ta interlayer to improve contact damage of the DLC but the effect of Ta doped DLC coatings has not been clearly investigated.

In this study, we deposited Ti:Ta-DLC graded composite coatings on Ti6Al4V and AISI M2 substrates to achieve high hardness, good adhesion and high fatigue resistance. Structural, mechanical, adhesion and fatigue properties of the coatings have been investigated.

2. Experimental details

Ti:Ta-DLC graded-composite coatings were deposited on Ti6Al4V

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Table 1
Deposition parameters of the Ti:Ta-DLC coatings.

Deposition parameters					
Coatings	Target currents		Substrate biased voltage (−V)	Working pressure (Pa)	Deposition Time (min)
	Ta	Ti			
Run 1	3	5	60	0.33	75
Run 2	4				
Run 3	5				

Gaz flow ratios for layers		
Layers	Ar/N_2	Ar/C_2H_2
TiN	0.45	0
TiTaCN	0.45	0.5
TiTa:DLC	4.15	0.3

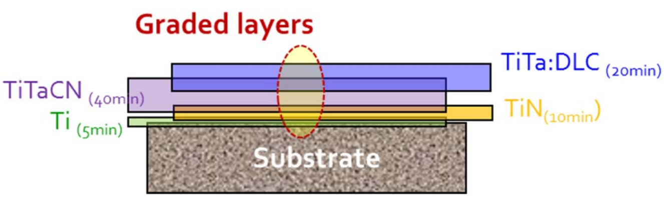

Fig. 1. The architecture structure of Ti:Ta-DLC coating.

and M2 substrates and glass wafers. The substrates were polished mechanically until the average roughness values R_a reached down to ~0.05 µm and then the substrates were cleaned with ethyl alcohol in ultrasonic bath and were etched in the 5% nitric acid solution. Closed field unbalanced magnetron sputtering system was used for deposited Ti:Ta-DLC coatings. Two Tantalum targets, two Titanium targets, N_2, C_2H_2 and Ar gases were used to growing Ti:Ta-DLC composite coatings. Ion cleaning process was conducted for 20 min to eliminate possible contamination and to increase adhesion between the substrate and the coating. The coating parameters of the deposition process are given in Table 1. Ta targets current changed gradually as 3A, 4A and 5A for Run1, Run2 and Run3 coatings respectively. The titanium target current was determined as 5A fixed value for all coatings. To obtain better adhesion and dense coating, pulsed-DC bias voltages were applied to the substrates as a constant value of −60 V. During the deposition, the working pressures were 0.33 Pa and the deposition process were completed in 75 min. The architecture structure of the graded-composite coating is given in Fig. 1.

The microstructure of the coatings, thickness and elemental compositions were determined via SEM and energy dispersive spectrometry (EDS) methods. The microhardness of the coatings was obtained with microhardness tester using Vickers indenter and 10gf load. To analyze crystallographic structure of the coatings X-Ray difraktometer was used with a Cu-Kα radiation source and the scan range was from 5° to 100°. To determine the bond structures of the carbon atoms in the DLC coatings, X-ray Photoelectron Spectroscopy (XPS) was used. The roughness of the samples and the coatings were evaluated by Mahr surface profilometer. The multi-pass scratch tests were occurred in dry atmosphere conditions with the Revetest Scratch Tester. The Rockwell-C indenter tip was used (120° apex angle, 200 µm tip radius) to scratch the coatings. The scratch length was 3 mm and bidirectional load (both forward and backward movement) was applied during the 250 pass cycles.

3. Results and discussion

3.1. Microstructure of the coatings

The crystal structure of the Ti:Ta-DLC coatings was analyzed with XRD and the results are given in Fig. 2. According to the XRD patterns there are many crystal orientations in the structure. The Ti based crystals are TiC(111), TiCN(111) TiN(200), TiC(220) and TiN (222). The dominant peak between these crystals is TiC(111) that has high hardness and good wear resistance. Additionally, the presence of TiCN (111) crystal provides further increase of mechanical and tribological properties of the coatings [17–19]. Looking at the Ta based crystals, TaN(110), TaC(111) and TaC(222) orientations were determined in the

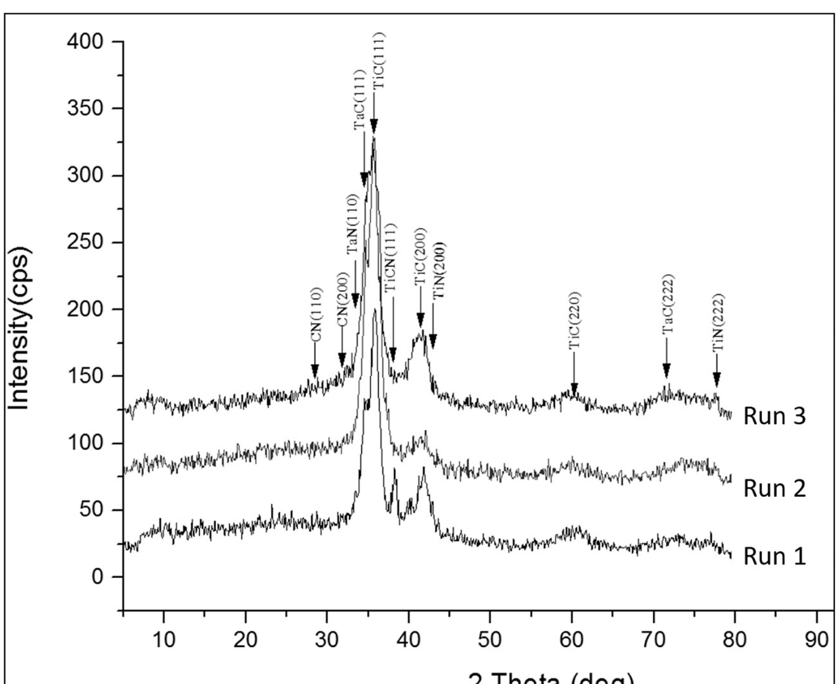

Fig. 2. XRD patterns of the Ti:Ta-DLC deposited coatings.