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Influence of the negative bias in ion plating on the microstructural and tribological performances of Ti–Si–N coatings in seawater

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ABSTRACT

The TiSiN coatings were deposited on Ti_6Al_4V alloy by multi-arc ion plating with different substrate negative bias to improve the tribological properties of titanium alloy in seawater. The TiSiN coatings have a coupled structure of amorphous Si_3N_4 and nanocrystalline TiN. The grain size decreases and the coatings become dense with the increase of the negative bias. The hardness of TiSiN coatings increases from 39 GPa to 47 GPa with the increase of substrate negative bias from 10 V to 40 V. The tribological tests reveal that the TiSiN coatings have a lower friction coefficient and higher wear rate in seawater compared with in atmosphere. Moreover, the wear rates increase with the increase of bias voltage. The TiSiN coating deposited at bias voltage of 10 V shows the best tribological properties in seawater.

1. Introduction

Titanium alloys have been widely used in manufacturing ships, submersibles, ocean exploration and marine equipment as the key components due to its lightweight, high strength, particularly excellent corrosion resistant in marine environment. However, the poor wear resistance has restricted the application of titanium alloy. Especially, some crucial frictional components (such as pump, hydraulic system, valve, gear, shaft and propeller) which are surrounded by seawater directly have to face the complex work condition containing both wear and corrosion [1–2]. Thus, excellent tribological resistance is crucial for the service life and safety of these components. It is a promising method to improve the tribological resistance by depositing coatings with excellent performance on substrates using PVD technology. TiN coating is extensively used to improve the wear resistance due to its low friction coefficient, good chemical stability and high hardness [2–7]. The element Si was incorporated into TiN coating to form the TiSiN coating, which has higher hardness and lower wear rate due to its special nanocomposite structure compared with the TiN [8,9]. S.Z. Li et al. had firstly reported the TiSiN coating deposited by PCVD using chlorides as source of Si and Ti [10]. Veprek et al. revealed a TiSiN coating with super hardness about 50–60 GPa [11], and the authors argue that the hardness enhancement attributed to the binary nc-TiN/a-Si_3N_4 nature of these coatings (nc- and a- means nanocrystalline and amorphous, respectively). The TiSiN coatings often were prepared by CVD [12], PCVD [10] and PVD [13–15] methods. However, for CVD processes, the requirement of poisonous gases ($SiCl_4$) and high deposition temperature (>600 °C) restricts its application. PVD techniques are considered more suitable to synthesis than the TiSiN coatings [13], such as unbalance magnetron sputtering [14] and electron beam ion plating [15]. Many researchers have reported the hardness enhancement mechanism, thermal stability and tribological behavior in atmosphere of the TiSiN coatings [16–18]. However, there is a lack of information on tribological behavior of the TiSiN coating in marine environment.

In this paper, the TiSiN coatings were deposited by multi-arc ion plating with different negative bias. The effects of substrate negative bias on the structure and tribological behaviors in seawater of the TiSiN coating were investigated.

2. Experimental details

The commercial Ti_6Al_4V alloy was used as the substrate. The samples with a size of 15 mm × 15 mm × 4 mm were polished to mirror and ultrasonically cleaned in acetone for 20 min before deposition. The chamber was pumped down to base pressure of 4×10^{-5} Pa. The TiSi (Ti 90 wt.% and Si 10 wt.%) target was used to prepare coatings by multi-arc ion plating system (Hauzer Flexicoat 850), The substrates were etched for 2 min to clean the impurities with negative bias of 900 V, 1100 V and 1200 V, respectively, in the gas of Ar (99.99%). Firstly, the thin TiSiN interlayer was deposited with a N_2 (99.99%) pressure of 3×10^{-2} Pa and bias negative voltage of 40 V, at temperature of 450 °C

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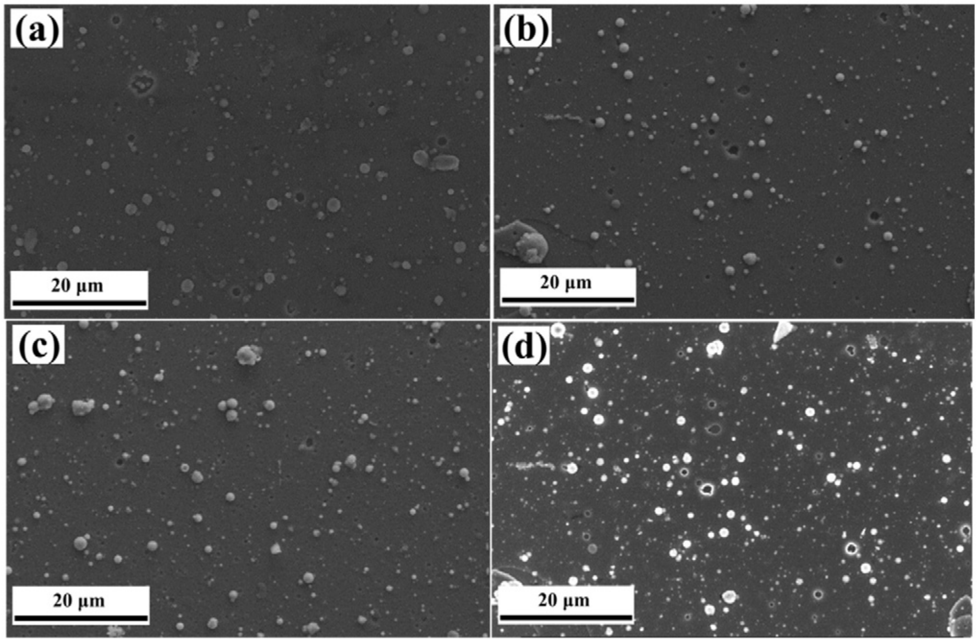

Fig. 1. Surface morphology of TiSiN coatings deposited with different negative bias: (a) 10 V (b) 20 V (c) 30 V (d) 40 V.

Table 1
Roughness and thickness of TiSiN coatings at different bias voltages.

Bias (−V)	10	20	30	40
Roughness (nm)	134.9 ± 1.89	110.2 ± 1.24	122.5 ± 1.37	138.4 ± 1.48
Thickness (μm)	1.8	2.0	1.7	1.2

for 10 min. Secondly, the TiSiN coatings were deposited with a target current of 60 A and a distance from the substrate to the target of 100 mm, the negative bias was 10 V, 20 V, 30 V and 40 V, respectively, for 120 min. During deposition, the temperature is fixed at 450 °C and nitrogen pressure is 3×10^{-2} Pa.

The phase structure was investigated by X-ray diffraction (Bruker D8X-ray facility) with Cu Kα radiation (λ = 0.154 nm). The scanning angle was ranged from 20 to 90°, every sample was scanned for 8 min. Field emission scanning electron-microscope (Hitachi S4800) and Zeiss large chamber scanning electron microscope (EV018) were used to observe the cross-section and wear track morphologies of the coatings. The element chemical states were determined by X-ray photoelectron spectroscopy (AXIS-ULTRA, Kratos) with Al (mono) Kα X-ray under 12 kV and 10 mA, the surface of these samples were etched about 2 min before XPS experiment. The structure was characterized by transmission electron microscope (FEI Tecnai F20). Hardness tests were measured in a MTS Nano G200 system with a Berkovich indenter using the continuous stiffness measurement (CSM).

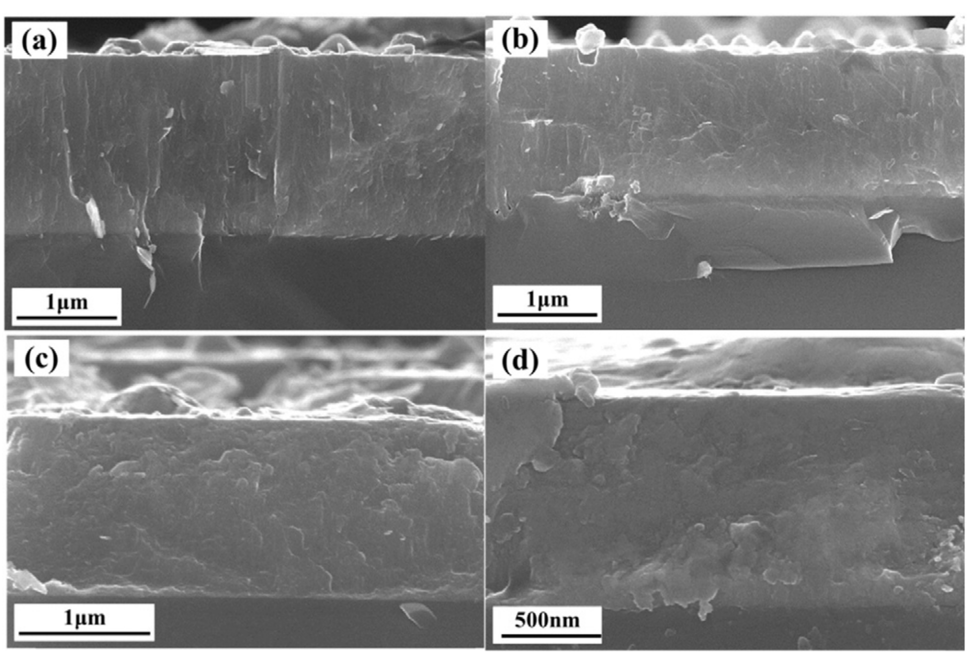

Fig. 2. SEM images of cross-section fractured TiSiN coatings with different negative bias: (a) 10 V (b) 20 V (c) 30 V (d) 40 V.