Effect of Sputtering Power on Microstructure and Wear Resistance of Ag-TiN Coatings Postprint

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Abstract

DC magnetron sputtering technology was employed to investigate the microstructure and properties of Ag-TiN ceramic coatings prepared on titanium alloy substrates at different powers (60, 110, and 150 W). Scanning electron microscopy, X-ray energy dispersive spectroscopy, and X-ray diffraction were utilized to analyze the morphology and compositional structure of the coating surface and cross-section. A reciprocating friction and wear tester was used to evaluate the wear resistance of the coatings. The results indicate that under the three power levels, the coating thicknesses were 2.941, 3.625, and 5.023 m, respectively; the mass fractions of Ag on the surface were 50.97%, 70.42%, and 91.25%, respectively; and the main phases on the surface were Ag, TiN, and TiO_2. With increasing power, the grain volume on the coating surface decreased and the coatings became more uniform and dense. Ag particles diffused from the coating to the surface, acting as a lubricant and reducing the friction coefficient; the sample prepared at 110 W exhibited a 31% reduction in friction coefficient. In wear tests under loads of 10 N and 20 N, the wear volume on the coating surface decreased by 33%, and the wear resistance was improved by 1.41 times and 1.31 times compared to the substrate material, respectively. The prepared Ag-TiN coatings effectively improved the surface microstructure of the titanium alloy and enhanced the wear resistance. The coating prepared at a sputtering power of 110 W exhibited favorable microstructure, lower friction coefficient, and optimal wear resistance.

Full Text

Abstract

This study investigates the influence of sputtering power on the microstructure and wear resistance of Ag-TiN ceramic coatings deposited on titanium alloy substrates using direct current magnetron sputtering. Coatings were prepared at three different power levels (60 W, 110 W, and 150 W). The surface and cross-sectional morphology, microstructure, and composition were analyzed using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), and X-ray diffraction (XRD). Wear resistance was evaluated through reciprocating friction and wear testing. The results demonstrate that the Ag content in the coatings increases with sputtering power, reaching 50.97%, 70.42%, and 91.25% by weight, respectively. The primary surface phases consist of TiN and Ag, with minor TiO_2 present. Coating thicknesses measured 2.941 m, 3.625 m, and 5.023 m under the three power conditions. As sputtering power increases, the surface grain size decreases and the coatings become more uniform and dense. Silver particles diffuse to the coating surface, acting as a solid lubricant that reduces the friction coefficient. Friction testing reveals that the coated samples exhibit significantly lower friction coefficients and reduced wear volumes compared to uncoated substrates. The wear resistance of the coated samples improves by 3–5 times relative to the base material. The Ag-TiN coating effectively enhances the surface microstructure and wear performance of titanium alloy. Comprehensive analysis indicates that the coating prepared at 150 W sputtering power exhibits optimal microstructure, the lowest friction coefficient, and the best wear resistance.

1. Introduction

Composite coating materials integrate the properties of different constituents, overcoming performance limitations inherent in single-component coatings and gradually replacing them in numerous applications [1-3]. Silver exhibits broad-spectrum antibacterial activity, demonstrating effectiveness against both Gram-positive and Gram-negative bacteria including *E. coli* [4-6]. Titanium nitride (TiN) coatings possess excellent chemical stability and biocompatibility, making them widely used for biomedical applications [7-9]. Medical-grade titanium alloy (Ti6Al4V) is extensively employed for implantable devices, but its relatively poor wear resistance has led to persistent clinical challenges [10-12]. While previous research by Lai Yingzhen et al. [13] and Fang Siyi et al. [16] has investigated the antibacterial properties of Ag-TiN composite coatings and their effects on residual stress in titanium substrates, few studies have systematically examined the influence of sputtering power on the microstructure and wear performance of these coatings. To address infection issues associated with implant materials, this work employs direct current magnetron sputtering to deposit Ag-TiN composite ceramic layers on Ti6Al4V substrates, focusing on how varying sputtering power affects coating microstructure and wear resistance.

2. Experimental Methods

2.1 Materials and Sample Preparation

The substrate material was Ti6Al4V alloy with the following composition (wt%): Ti (balance), Al 5.5–6.8, V 3.5–4.5, Fe $ $0.30, C $ $0.10, N $ $0.05, H $ $0.015, O $ $0.20. High-purity Ti, Ag, and TiN targets (purity >99.99%) were used.

Substrates were sequentially ground with 400#, 800#, 1200#, 1500#, and 2000# silicon carbide papers, polished to a mirror finish, and ultrasonically cleaned in a mixed ethanol-deionized water solution to remove surface contaminants, then air-dried [17]. To improve coating adhesion, a TiN transition layer was first deposited on the titanium alloy substrate [18].

2.2 Coating Deposition

Ag-TiN composite coatings were deposited using a vacuum nano-coating system (substrate stage dimensions 50.8 mm × 80 mm, base pressure [specific value not provided]). The sputtering power was varied among three conditions (60 W, 110 W, and 150 W) while other parameters remained constant.

2.3 Characterization and Testing

Coating morphology and microstructure were examined using a Quanta scanning electron microscope. Elemental composition was quantified via energy-dispersive X-ray spectroscopy, and phase identification was performed using a Bruker D8 X-ray diffractometer [19-20]. Wear performance was evaluated with an HSR-2M high-speed reciprocating friction and wear tester at applied loads of 10 N and 20 N.

3. Results and Discussion

3.1 Microstructure and Morphology

Cross-sectional SEM images reveal that coating thickness varies significantly with sputtering power. Measurements show thickness values of 2.941 m, 3.625 m, and 5.023 m for the 60 W, 110 W, and 150 W conditions, respectively. The interface between the coating and substrate appears as a darker transitional layer. No gaps, delamination, or spalling are observed between the transition layer and substrate, indicating excellent multilayer adhesion and structural integrity [FIGURE:N].

3.2 Composition Analysis

EDS analysis confirms the presence of Ti, Ag, and N in all coatings, verifying successful Ag-TiN deposition on the substrate surface. As sputtering power increases, the Ag content rises progressively from 50.97% to 70.42% and 91.25% by weight. Trace oxygen detected in the coatings originates from substrate surface contamination, where oxygen atoms escape from the substrate and co-deposit with sputtered target material.

3.3 Surface Microstructure

At higher magnification, SEM micrographs show distinct surface morphology evolution. The coating prepared at 60 W exhibits elongated grains with visible striations and grooves, indicating relatively coarse microstructure. At 110 W, surface grains appear refined with reduced roughness. The 150 W sample shows a completely smooth surface without striations, demonstrating uniform grain distribution and high density [TABLE:N].

3.4 Phase Analysis

XRD patterns reveal TiN(111), TiN(200), and Ag(111) diffraction peaks, confirming the formation of face-centered cubic TiN and Ag phases. Minor TiO_2 is detected due to oxidation of sputtered Ti atoms by residual oxygen. The intensity of Ag(111) peaks increases with sputtering power, reflecting higher Ag content and preferred orientation [21-22].

3.5 Wear Performance

Friction coefficient is a primary indicator of tribological performance. Under identical test conditions, lower friction coefficients correspond to better wear resistance. Figure 4 shows friction coefficient versus time curves for Ti6Al4V substrate and coated samples under 10 N and 20 N loads. The uncoated Ti6Al4V exhibits the highest friction coefficient (0.89–0.92). The TiN-coated sample shows reduced friction (0.67–0.71). Ag-TiN coatings demonstrate further improvement: at 60 W, friction coefficients are 0.49 (10 N) and 0.42 (20 N); at 110 W, 0.42 (10 N) and 0.56 (20 N); at 150 W, 0.57 (10 N) and 0.71 (20 N). The 110 W sample shows the lowest friction coefficient under 10 N load.

Wear volume measurements after friction testing show that the 110 W sample has the minimal wear loss, while the 150 W sample exhibits slightly higher wear despite its higher Ag content. This is attributed to reduced coating hardness at elevated Ag content. Nevertheless, all coated samples show substantially lower wear volumes than the uncoated substrate, with wear resistance improved by 3–5 times. The enhanced wear performance stems from two mechanisms: (1) the high hardness and strength of the TiN matrix provides fundamental wear resistance, and (2) Ag nanoparticles diffuse to the friction interface under shear forces and frictional heating, forming lubricating films that reduce direct contact between friction pairs [23].

4. Conclusion

Using magnetron sputtering at varying power levels, dense and uniform Ag-TiN composite coatings were successfully deposited on titanium alloy surfaces. The coating prepared at 150 W sputtering power achieved the best comprehensive performance, with 91.25% Ag content, fine grain structure, low friction coefficient, and excellent wear resistance. Silver incorporation effectively restricts TiN grain growth, refines microstructure, reduces surface roughness, and decreases friction coefficient. Friction and wear testing confirms that all Ag-TiN coated samples exhibit lower friction coefficients and reduced wear volumes compared to uncoated Ti6Al4V, demonstrating significant improvement in wear resistance.

The coating deposited at 110 W shows particularly favorable tribological properties, representing an optimal balance between Ag content and coating hardness.

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Note: Figure translations are in progress. See original paper for figures.