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Special Issue: TRIBOINDIA 2023

Institution of MECHANICAL ENGINEERS
Journal of ENGINEERING TRIBOLOGY

Proc IMechE Part J:
J Engineering Tribology
1–18
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DOI: 10.1177/13506501241282751
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Advancements in biomedical coatings: A comprehensive review of DC magnetron sputtering on Ti–6Al–4V alloy

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Abstract

This study investigates the application of DC magnetron sputtering (MS) technology for producing TiN and ion-substituted Ca-P coatings on dental implant materials, demonstrating ultimate tensile strength (UTS) of 887 MPa, a modulus of elasticity of 11.3×10^6 MPa. The influence of various physical vapor deposition (PVD-MS) parameters—such as substrate temperature, post-heat treatment, deposition duration, discharge power, and bias voltage—on the characteristics of these coatings is examined. The research evaluates the advantages and limitations of PVD-MS in fabricating TiN and Ca-P coatings, with an emphasis on their impact on surface topography and chemical composition, which are critical factors influencing cellular behavior. The study reveals that while ion-substituted HA coatings can enhance cell adhesion, they may also exhibit cytotoxic effects, potentially limiting cell growth. It compares osteogenic cell proliferation rates between low-crystalline HA coatings and highly crystalline variants on Ti-based substrates, highlighting significant performance disparities. Additionally, PVD-MS demonstrates robust adhesion capabilities and facilitates the incorporation of therapeutic ions, effectively replicating bioapatite properties. The addition of coating on the substrate promotes additional strengthening mechanisms of the layers, leading to improved wear resistance compared to an alloyed substrate. Estimated values for hardness range between 7.2 and 8.4 GPa, and for Young's modulus, they range from 126 to 162 GPa. The study highlights the potential of PVD-MS in creating nanostructured Ca-P coatings on biodegradable metals, alloys, and polymeric biomaterials. This technology improves corrosion resistance, biocompatibility, chemical stability, wear resistance, and overall performance in various biomedical applications.

Keywords

Ti–6Al–4V alloy, PVD-MS, biocompatible coating, calcium phosphate, hydroxyapatite coating, Ti/N coating

Date received: 8 May 2024; accepted: 23 August 2024

Introduction

Titanium and its alloys, such as Ti-6Al-4V, are essential in medical applications due to their unique combination of properties crucial for implants.[1] Their high strength-to-weight ratio ensures that implants can endure biomechanical stresses without being overly burdensome. This strength is vital for applications like bone plates, hip and knee replacements, and dental implants, where durability and stability are critical. Another important feature is biocompatibility. Titanium integrates seamlessly with body tissues, promoting healing and reducing the risk of rejection. This property supports long-term implant success through osseointegration, where bone grows around the implant, securing it firmly.[2] Additionally, titanium alloys exhibit excellent corrosion resistance, vital for implants exposed to bodily fluids and varying environmental conditions.[3] This resistance maintains the structural integrity of implant over time, contributing to its longevity and reliability in medical use. In summary, titanium and its alloys are crucial in modern medicine, offering durable, biocompatible solutions that enhance patient outcomes and quality of life across various surgical applications.[4] While these alloys naturally form surface oxide layers that promote positive biological responses, pure titanium implants can corrode in the body, releasing metal ions and hindering bone integration.[5–7]

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