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Investigation of the Bio functionality of Hydroxyapatite (HA) and Bioactive Glass Coatings on the Ti-6AL-7Nb Implants

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ABSTRACT

Bioactive coatings of hydroxyapatite (HA) and bioactive glass (BG) were deposited onto Ti-6Al-7Nb substrates by electrophoretic deposition (EPD). The effects of BG concentration (8–14 g/L) and HA/BG ratios (70/30 and 30/70 wt%) were examined in terms of morphology, wettability, corrosion resistance, and bioactivity.

Surface analyses (SEM, EDS, XRD, contact angle) and electrochemical testing in simulated body fluid (SBF) showed that increasing HA content improved crystallinity, surface coverage, and adhesion, while reducing cracking. For the 8 g/L HA coating, the corrosion rate was reduced from 7.100×10^{-3} mpy (uncoated alloy) to 5.544×10^{-3} mpy, and further to 2.841×10^{-3} mpy after immersion. Wettability was also enhanced, with contact angles below 5° compared to 84.25° for the bare alloy.

Rising BG concentration improved coating uniformity, reduced porosity, and increased thickness (41.1–57.3 μm). A higher zeta potential (18.47 mV) and lower corrosion rate (4.509×10^{-3} mpy) were achieved at 14 g/L BG, with stronger adhesion attributed to improved particle interlocking.

Hybrid coatings displayed composition-dependent performance. HA-rich coatings produced thicker and denser films with superior early-stage bioactivity, while BG-rich coatings provided more stable long-term corrosion resistance, compact apatite layers, and improved sealing. Both hybrid types exhibited excellent hydrophilicity (~5.9° contact angle) and strong adhesion (5B rating).

Antibacterial activity was confirmed, with inhibition zones up to 25 mm for E. coli and 23 mm for S. aureus. These findings demonstrate that BG concentration and HA/BG ratio critically influence coating integrity and biological performance, making such coatings promising for biomedical implant applications.

Chapter One

Introduction

1.1 Background

In recent years, both young and old people have become more in need of bone replacement. The human body's damaged tissues can heal themselves after being harmed. Both the bone and the surrounding tissues' ability to function are lost when a broken bone or tissue is too big to be repaired. Innovative, alternative materials for bone restoration may be used in such a situation[1]. The technique of electrophoretic deposition (EPD) is versatile. The EPD process has many demonstrated benefits, such as the ability to produce advanced materials, nanostructures, thin coatings, and functionally graded materials. EPD involves minimal amounts of initial materials, inexpensive equipment, and simple design tools[2].

EPD typically occurs in a two-electrode cell and is typically conducted at ambient temperature. EPD works with eco-friendly products or calls for extra safety measures in numerous industrial operations[3]. However, four features need to be carefully matched in order to get an effective coating. These include meticulously choosing cutting-edge materials, having a thorough understanding of both independent and dependent processing factors, designing the system correctly, and comprehending all the concepts needed to regulate the phenomena. All of these qualities should be controlled by theoretical and experimental experience. Enzymes, bacteria, and cells are among the biological fields where EPD has promising advanced applications. Researchers from numerous colleges and specialized institutes throughout the world put a lot of effort into creating and improving various forms of EPD coatings[4, 5].

Although it is not a novel approach, EPD works well for depositing electrode-charged particles from a colloidal suspension in a stable state while applying direct current. This approach is composed of two steps in theory. The movement of charged particles in a solvent liquid is the initial stage. An applied electric field (electrophoresis) should be present throughout this step. To create an adherent layer on the electrode, the particles must coagulate (deposit) in the second stage[4, 6].

One of the drawbacks of employing metals as a biomaterial was that they were unable to regulate the flow of ions into the body and were encapsulated by fibrous tissues, which caused the implant to migrate and possibly loosen. Therefore, these materials have to be modified in order to be suitable as implants or as bioactive coatings for metallic implants in order to address these issues. Inducing integration and minimizing the discharge of undesirable metallic ions through the coating barrier effect are crucial[7, 8]. To change the surface characteristics of metallic implants, a variety of coating techniques are employed, including electrophoretic deposition, sol-gel, and plasma spraying. Because it was one of the most successful and efficient methods for fabricating, the EPD approach was both fascinating and significant useful tools and materials.

The hydroxyapatite (HA) coating is the most significant bio-ceramic coating. Because of its special biocompatibility and bioactivity qualities, stainless steel can be utilized in the majority of medical and biomedical applications[9, 10]. One of the most important compounds in the human body is stoichiometry hydroxyapatite (Ca10 (PO4)6(OH) 2), which is derived from calcium phosphate.

They have been widely employed in the fields of orthopedics and dentistry for a range of biological purposes. The primary benefit of hydroxyapatite ceramic is its better osteoconductivity and biocompatibility due to its chemical resemblance to mineral components. However, HA prohibits its application in severe implant bearing contacts due to its low fracture toughness and evident brittleness[11, 12].

Because of its physicochemical characteristics and resemblance to the extracellular matrix of bone and cartilage, chitosan has been used as a coating material for surface modification of orthopaedic implants, among its many other applications in biomedical research. Among the attributes include chemical tolerance, antibacterial activity, biodegradability, non-toxicity, and biocompatibility[13].

1.2 The aim of Study

To develop and evaluate hybrid hydroxyapatite (HA) and bioactive glass (BG) coatings on Ti-6Al-7Nb substrates using electrophoretic deposition (EPD), and to investigate how BG concentration and HA/BG ratio affect the coatings' structural, corrosion, antibacterial, and biological performance for implant applications.

1.3 Objective of study

1. To fabricate HA, BG, and HA/BG hybrid coatings on Ti-6Al-7Nb substrates using EPD.

2. To study the effect of BG concentration (8–14 g/L) and HA/BG ratios (70/30 and 30/70 wt%) on coating morphology, thickness, porosity, and crystallinity.

3. To analyze surface characteristics using SEM, EDS, XRD, and contact angle measurements.

4. To assess electrochemical performance in simulated body fluid (SBF) and determine corrosion resistance.

5. To evaluate wettability and adhesion strength of the coatings.

6. To investigate the in-vitro bioactivity of the coatings by apatite formation in SBF.

7. To examine antibacterial activity of the coatings against E. coli and S. aureus.

8. To establish the relationship between HA/BG composition and coating performance, identifying optimal conditions for biomedical implant applications

1.4 The Organization of the Study

This research is categorized into five chapters and it might be presented in the following way:

Chapter one: includes the introduction and aims of the present work.

Chapter two: Theoretical Background and Literature Review

Chapter three: Experimental Work

Chapter four : Results and Discussion

Chapter five: Conclusions and Recommendation