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Doctoral Dissertation: *Modification of the surface of titanium and its alloys to improve functional properties*

Abstract

Titanium implants play a key role in modern regenerative medicine; however, their susceptibility to corrosion in physiological environments and limited bioactivity remain significant challenges in implantology. Consequently, there is a growing interest in functional protective coatings that not only enhance the durability of implantable materials but also support their integration with biological tissues.

This Doctoral Dissertation aimed to develop, fabricate, and comprehensively characterize protective coatings based on vinyltrimethoxysilane (VTMS) and tetraethoxysilane (TEOS), deposited on the surfaces of commercially pure titanium Grade 2 and titanium alloys Ti6Al4V, Ti6Al4V 3D SLS, and Ti13Nb13Zr. The research focused on evaluating the applicability of the obtained coating systems in biomaterials engineering, with particular emphasis on their anticorrosion and physicochemical properties in environments simulating physiological conditions.

The coatings were produced using the sol-gel method and applied via the dip-coating technique in a layer-by-layer approach, without the need for additional thermal curing at elevated temperatures. This approach enabled controlled surface modification without adversely affecting the substrate properties. Both single- and multilayer coating configurations with varying VTMS:TEOS ratios were developed, and systems modified with hydroxyapatite (HAp) and the non-ionic surfactant Triton X-100 were also investigated to improve microstructure, adhesion, and uniformity of the coatings.

Material characterization included morphological analysis (SEM, optical microscopy), adhesion testing (Scotch™ tape test), surface roughness measurements (AFM, digital microscopy), coating thickness evaluation, chemical composition analysis (EDX, FTIR), and

corrosion resistance testing (open circuit potential – OCP, potentiodynamic curves, polarization resistance). The results confirmed that silane-based coatings significantly enhance the corrosion resistance of the tested substrates by shifting the corrosion potential toward more noble values and reducing anodic and cathodic current densities. Particularly favorable properties were observed for three-layer coatings, with a balanced VTMS:TEOS ratio and for coatings modified with hydroxyapatite.

The resulting materials exhibited smooth, uniform surfaces and high adhesion to the substrate, indicating their application potential for titanium implant modification. The study identified optimal process parameters, such as the number of layers and the proportions of precursor components, which significantly influence the durability and functionality of the protective coatings. The findings provide a strong foundation for further research aimed at implementing such solutions in clinical practice, particularly in orthopedics and implantology, where high mechanical performance, corrosion resistance, and biocompatibility are required.