SURFACE MORPHOLOGY AND MECHANICAL PROPERTIES OF TITANIUM LAYERS MIXED WITH CALCIUM AND PHOSPHORUS

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Abstract

Titanium layers doped with biogenic elements attract much attention due to their ability to enhance the biological integration of implant materials. However, the addition of biogenic elements to the coating/layer changes its composition, structure, properties, and surface morphology, which affects their application possibilities. Therefore, the research and surface characterization of such layers is needed. In the present work, the mixed titanium layers with calcium and phosphorus have been synthesized by a dual electron beam evaporation method. The effect of doping in these mixed-titanium layers on their surface morphology and mechanical properties has been investigated. Atomic force microscopy was used for morphological characterization and nanoindentation was used to measure the mechanical properties (indentation hardness and reduced modulus). The surface layers are characterized in connection by tuning the deposition conditions and increasing dopant content.

Keywords: Titanium, doping, morphology, mechanical properties

1. INTRODUCTION

Titanium and its alloys stand out and are used in many engineering applications in the aerospace, chemical, and biomedical industries, due to their excellent strength-to-density ratio, biocompatibility, and high corrosion resistance in many environments [1-3]. Surface properties, not only for titanium and its alloys, depending on the structure, morphology, and chemical composition of their surface. Many methods exist to increase surface properties by changing the morphology and chemical composition of titanium. For example, advanced methods using accelerated ions, such as ion implantation, ion beam-assisted deposition, magnetron sputtering, and plasma-assisted chemical vapour deposition, can be used to improve these surface properties [4-7]. The paper is focused on the dual electron beam evaporation method. Using this method, a layer of titanium with calcium and phosphorus was deposited on commercially pure titanium grade 2. Previously, [8-9] showed an increase in the biocompatibility of titanium by adding phosphorus and calcium. Calcium phosphate and hydroxyapatite help to create chemical bonds with the human bone tissue and optimal bone integration of an implant. Implant fracture due to mechanical failure is related to biomechanical incompatibility. For this reason, biomedical implants require specific mechanical properties, such as hardness, Young´s modulus, elongation, or tensile strength, close to the mechanical properties of human bone.

This work presents the effect of the applied layer with different concentrations of the mixture of titanium, calcium, and phosphorus on the morphology and mechanical properties. Surface morphology was monitored by atomic force microscopy (AFM), and indentation hardness and reduced modulus were investigated by nanoindentation.

2. EXPERIMENTAL

In this study commercially pure titanium grade 2 (CPTi) was used. Samples 5 mm in height and 14 mm in diameter were cut from the CPTi bar and then ground with silicon carbide abrasive papers with grain sizes from 320 to 1000. The samples were mechanically polished using ChemoMet, a soft, porous, chemically resistant synthetic polishing pad, and non-crystallizing amorphous 0.02μm colloidal silica suspension MasterMet2 with a little bit of hydrogen peroxide. The mixed titanium layers with calcium and phosphorus were synthesized by a dual electron beam evaporation method. The scheme of deposition of layers with different concentrations of BTP was the same as in the previous experiment in [10], however, with a BTP target instead of a calcium target and deposition temperature of 500 °C without the assistance of oxygen. The BTP content was controlled by the deposition rate of targets. The TI 950 TriboIndenter® nanomechanical instrument with dynamical mode CMX was used for depth profiling of the deposited layers. Atomic force microscopy was used to characterize the surface morphology. AFM measurements were performed in contact mode.

3. RESULTS AND DISCUSSION

3.1. Surface morphology

The morphology of the deposited layers was measured by atomic force microscopy (AFM). **Figure 1** presents roughness measurements of BTP concentrations of 40, 60, 80, and 100 %. BTP concentrations of 40, 60, and 80 % were measured to have a roughness of around 14 nm. The lowest roughness of approximately 6 nm was achieved at a concentration of 100 % BTP. Morphological changes were also confirmed by AFM images, **Figure 2**. A change in morphology was documented for all BTP concentrations. The formation of a new similar characteristic morphological structure is typical for 40 and 60 % BTP concentrations. As the concentration increases, the structure changes, and the surface becomes smoother.

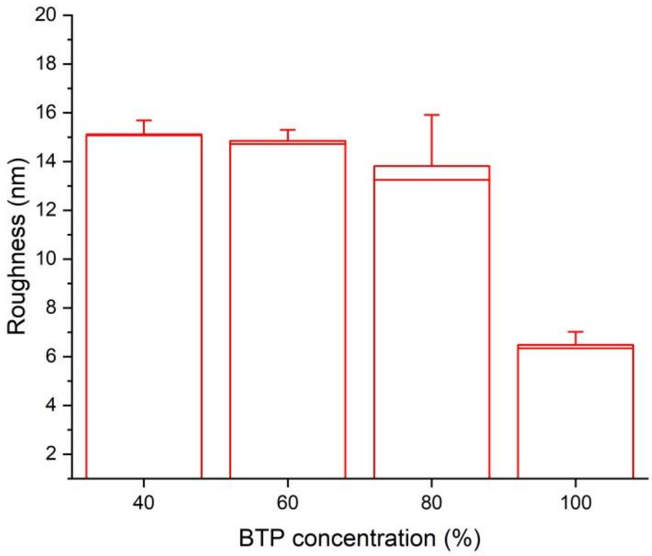
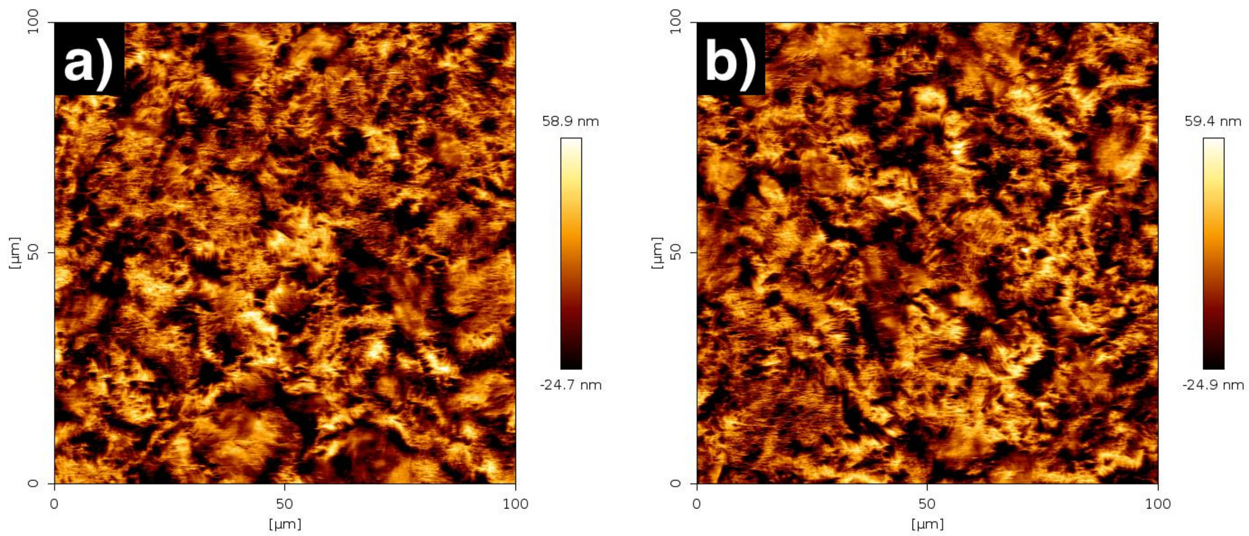


Figure 1 Average roughnesses of different BTP concentrations obtained from AFM topographic measurements



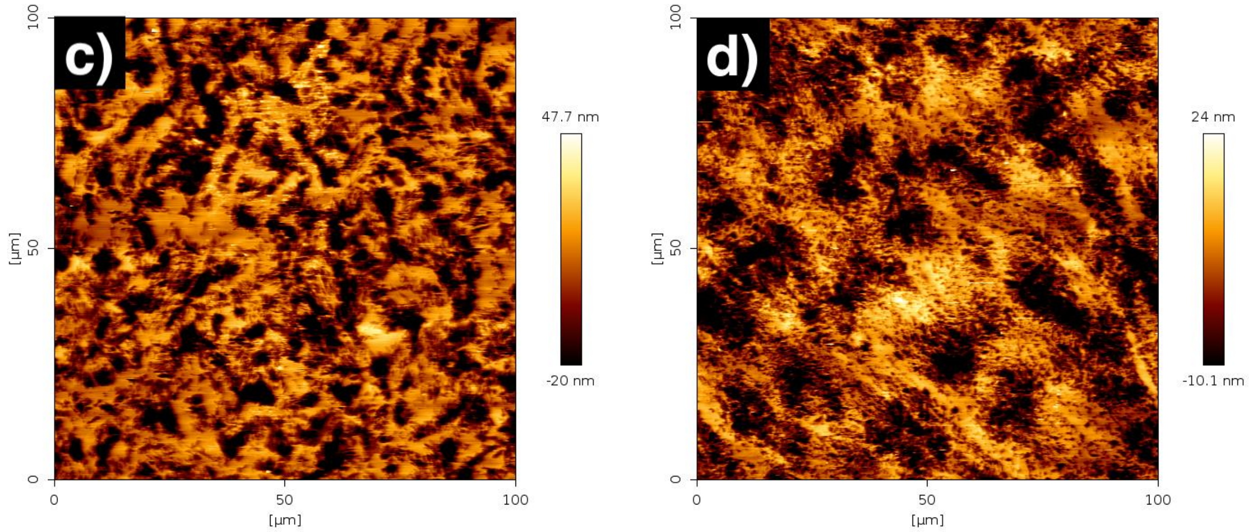


Figure 1 AFM images of 40 % BTP (a), 60 % BTP (b), 80 % BTP (c) and 100 % BTP (d)

3.2. Mechanical properties

We measured the mechanical properties (indentation hardness and reduced modulus) of the deposited layers using the nanoindentation method. In both cases, the concentration of 40 % BTP achieved the highest values. The reduced modulus of the 40 % BTP layer was approximately 140 GPa and the indentation hardness was roughly 10.2 GPa. The results of measurements for 60 and 100 % BTP were roughly similar. The reduced modulus was 110 GPa and the hardness was approximately 6 GPa. The 80 % BTP concentration had 105 GPa of reduced modulus and 5.5 GPa of indentation hardness.

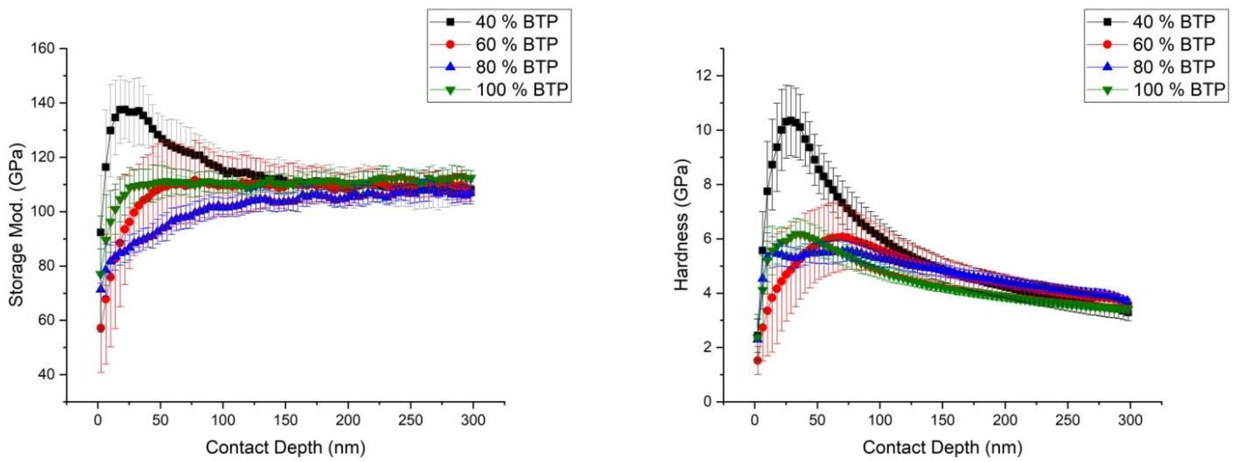


Figure 3 Average roughnesses of different BTP concentrations obtained from AFM topographic measurements

4. CONCLUSION

The influence of the BTP concentration on the surface morphology and mechanical properties has been demonstrated. The deposited mixed titanium layers with calcium and phosphorus create a new characteristic morphology that smooths out with increasing concentration. As the concentration of BTP increases, the surface roughness decreases. The lowest roughness of approximately 6 nm close to the previously polished surface has a concentration of 100 % BTP. A concentration of 40 % BTP conclusively achieves the highest values of hardness (approximately 10.2 GPa) and reduced modulus (approximately 140 GPa).

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