BIOTRIBOLOGICAL BEHAVIOR OF AG-ZRC\textsubscript{x}N\textsubscript{1-x} COATINGS AGAINST UHMWPE FOR JOINT PROSTHESES DEVICES

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ABSTRACT

This study aims to evaluate the structural, mechanical and tribological properties of zirconium carbonitrides (ZrC\textsubscript{x}N\textsubscript{1-x}) coatings with embedded silver nanoparticles, produced with the intention of achieving a material with enhanced multi-functional properties, including mechanical strength, corrosion resistance, tribological performance and antibacterial behaviour.

Keywords: sputtering, boundary lubrication, hydrophilic/hydrophobic character, albumin.

INTRODUCTION

Multifunctional coatings are being developed in order to improve the performance of current materials used in the medical devices field. The chemical inertness of the materials has been usually achieved by coating the devices with very low reactive ceramic material such as diamond-like-carbon materials \cite{1}, nitrides \cite{2} or oxides \cite{3}, while the antimicrobial capabilities have been achieved by introducing antimicrobial agents, such as silver \cite{4-6}. The tribological properties, on the other hand, are strongly dependent on the combination of the materials and lubricant used in the system. Studies about the influence of the different components of the simulated body fluid demonstrate that the adsorption of proteins strongly affects the wear and coefficient of friction (COF) of the system, depending on the ability of the surface to adsorb such molecules.

Among the large MeCN family of materials, ZrC\textsubscript{x}N\textsubscript{1-x} has been proven to have tunable properties depending on the non-metallic elements contents, altering the hardness, friction coefficient, and biocompatibility in a wide range\cite{7-8}. However, in order to provide the system with antimicrobial capabilities it is necessary to add an antimicrobial agent, such as silver, widely used and proven to be efficient. The aim of this work is to evaluate the influence of the chemical, structural and morphological properties of Ag-ZrC\textsubscript{x}N\textsubscript{1-x} films on the tribological performance against UHMWPE as counterpart in a Hank’s balance salt solution with 10 g L\textsuperscript{-1} albumin. This analysis will help to assess the viability of this system to be used in the field of prosthetic devices.

RESULTS AND CONCLUSIONS

Ag-ZrC\textsubscript{x}N\textsubscript{1-x} coatings were produced by DC reactive magnetron sputtering, varying the silver content between 0 and 20 at. %. The coatings exhibit crystalline ZrC\textsubscript{x}N\textsubscript{1-x} phase, crystalline silver nanoparticles and amorphous carbon phases. The results show a linear correlation between film hardness vs. ZrC\textsubscript{x}N\textsubscript{1-x} phase percentage. The hardness reduction with the
diminution of the $\text{ZrC}_x\text{N}_{1-x}$ phase percentage in the film, points out the ratio between hard and soft phases as the key-feature controlling the hardness properties, independently of the relative proportion between the silver and amorphous carbon phases. Among the Ag-$\text{ZrC}_x\text{N}_{1-x}$ samples, a significant reduction in the COF is observed when a-(C,N) is present. This diminution could be explained in a boundary lubrication regime (the one being expected in these lubricated tests), since the presence of this phase between surface asperities in close contact, where the liquid media could not get access or be hindered, would lead to a decrease in the friction. The COFs revealed a dominant ploughing mechanism on the friction forces dependent on the roughness and hardness of the films.

In addition to material properties, the composition of the fluid is known to play an important role in the measurement of the COF of the tribological system due to chemical and/or physical interaction with the material surface. Albumin has demonstrated to protect the surface of the materials against wear; however, its role on the COF is not well understood.

The UHMWPE wear rate did not exhibit significant differences between the samples, hampering the analysis of the surface roughness, hardness and COF effects on the polymer wear, probably explained due to the formation of a protective albumin layer adsorbed on the materials surface. Nonetheless, the UHMWPE wear rate shows a particular trend as a function of the silver content, indicating that the wear of the UHMWPE increases by increasing the silver content in the films. Recent investigations have found that silver nanoparticles on surfaces delay the adsorption of the albumin [9] and, therefore, the system may be less protected by the albumin as the silver nanoparticles increase in the material. The hydrophobic character of the samples also influences the albumin adsorption, thus, the high wear rate obtained for the ZrCN sample is also due to low albumin adsorption as it is indeed the single sample showing a hydrophilic character.

In summary, the wear of the soft UHMWPE material results from the balance between abrasive wear and plastic deformation, as determined by the film hardness, microasperities and debris particles, and boundary lubrication by albumin, controlled by the silver content and hydrophilic/hydrophobic character.

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