Short Communication

iMedPub Journals
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Journal of Clinical & Experimental Orthopaedics
ISSN 2471-8416

2021
Vol. 7 No. 7: 77

Multi-layer PVD coatings for longer lasting orthopaedic implants: A tribocorrosion evaluation

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Citation: Raisa C, Joseph B, Peter A, Bertram M. Multi-layer PVD coatings for longer lasting orthopaedic implants: A tribocorrosion evaluation J Clin Exp Orthop Vol. 7 No. 7: 70.

Abstract

Bone injuries coupled with a longer life expectancy necessitate the increased longevity of implanted biomaterials in patients suffering from bone diseases such as arthritis and osteoporosis. CoCrMo alloys have been widely employed as bearing surfaces in metal-on-metal (MoM) orthopaedic implants given their optimal mechanical properties and high corrosion resistance, as well as their relatively low wear rates and the post-operative stability. Loss of material by corrosion-wear of the hip joint and metal ion release into the blood stream are of prime concern as these can cause adverse reactions in the human body such as inflammation and bone erosion as well as loosening of the implant. This study aims to reduce the material loss at the bearing surfaces by the application of a multi-layer PVD coating on an ASTM F-1537 CoCrMo substrate. A 2.3 µm thick CrN coating was deposited on top of a 3.6 µm CoCrMo precipitate free supersaturated metastable solution of carbon, otherwise known as S-phase (S), by magnetron sputtered PVD. The coated samples designated as CrN/S, displayed a higher hardness and they retained their topography in nano-scratch tests relative to the uncoated CoCrMo substrate under the same conditions.

Keywords: osteoporosis; arthritis; bone erosion

Received: Nov 08, 2021, **Accepted:** Nov 18, 2021, **Published:** Nov 28, 2021

Introduction

Tribocorrosion tests for uncoated CoCrMo samples against uncoated CoCrMo counterfaces as well as for coated samples against coated counterfaces were conducted in Ringer's solution as well as in diluted Foetal calf bovine serum at 37±1 °C under reciprocating sliding conditions. Results show that under all applied potentials and in both solutions, the coated tribopairs when compared to the uncoated ones exhibited a significant decrease in material loss and excellent resistance to catastrophic failure by tribocorrosion. Figure 1 outlines the improvement exhibited by the coated samples under anodic conditions; the coated samples exhibiting a smaller wear scar and mostly polishing wear as opposed to the uncoated samples, in both solutions.

Austenitic stainless steel is characterised with a nanometric self-healing oxide film which naturally forms on its surface and protects the bulk material from corrosion. This oxide film is mechanically worn by the rubbing action of the femoral head against the acetabular component. The tailoring of implant surfaces using various techniques, including Physical Vapour Deposition (PVD), are used to mitigate this damage. PVD allows the surface properties to be enhanced without compromising the mechanical characteristics of the substrate material. The versatility of PVD enables the synthesis of coatings with different chemistries and structures. Most of the reported studies have been oriented towards mono-layer PVD coatings. The full potential of PVD that enables the synthesis of different coatings architectures with possible enhanced performance to mono-layer coatings has yet to be explored. S-phase, also known as expanded austenite, is a precipitate free, supersaturated, metastable solid solution of nitrogen or carbon in a face centred cubic chromium-containing alloy. S-phase layers have generally been produced on austenitic stainless steel and CoCrMo alloys via low temperature diffusion treatments such as carburising and nitriding.

In this work, PVD is used to produce CoCrMo supersaturated with carbon atoms (S-phase) at temperatures far below the sensitisation limit. Supersaturated metallic systems were previously shown to undergo significant oxidative wear (Type I corrosion-wear) damage but display.higher load support than the base alloy . PVD sputtered CoCrMo(C) S-phase has only received limited investigation for biomedical implants since previous studies have focused mostly on the Fe-Cr-Ni S-phase produced on metallic alloys via thermochemical treatments.

Previous works have shown that CrN coatings displayed excellent resistance to cyclic passive film breakdown and regeneration (Type I corrosion-wear) resulting in mitigation of material losses via this mechanism. CrN coated metallic biomaterials were however susceptible to accelerated corrosion attack of the substrate or coating-substrate interface resulting in blistering damage on stainless steel and catastrophic failure of the coating (Type II corrosion-wear). In a recent investigation of CoCrMo metal-on-metal PVD TiNbN coated bearings, which were retrieved 53 months after implantation, it was determined that the coating exhibited third body wear and delamination. Failure at the coating-substrate interface might have been induced by a mild form of Type II corrosion-wear damage . A strategically designed dual layer coating to mitigate the formation of paths for the solution to reach the substrate-coating interface can alleviate Type II corrosion-wear while maintaining a high resistance to Type I corrosion-wear. In this work, CrN on CoCrMo(C) S-phase were deposited via PVD to form a CrN/S dual layer on biomedical grade stainless steel. The CoCrMo(C) S-phase is intended to provide better load support to the top CrN layer with excellent resistance to Type I corrosion-wear damage. This underlayer shall mitigate micro-cracking of the CrN layer; a potential precursor for coating-substrate interfacial corrosion that causes Type II corrosion-wear damage. This dual layered coating helps to address the current concern of metallic ion release into the blood stream and the generation of wear particles at the bearing surfaces of the metallic implants . The tribocorrosion of the CoCrMo(C) S-phase layer and its mechanical properties were also studied on specimens by depositing the layers in reverse order. The study of the latter was included to get better scientific insight on the potential degradation mechanisms and enable a comprehensive study of the tribocorrosion performance of both coating layer combinations.

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