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Tribological characterization of microarc oxidized alumina coatings for biological applications

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A B S T R A C T

Coatings with high wear and corrosion resistance are desirable in tribological and biological applications. In an attempt to develop such coatings, we used microarc oxidation (MAO) method to generate noble coatings of alumina on aluminum alloys. This paper reports our tribological investigations on these coatings with a pin-on-disk tribometer in synthetic biofluid. The frictional behavior and wear mechanisms were studied through surface characterization using a scanning electron microscope and a surface profilometer. It was found that the MAO coatings were highly wear resistant in the biofluid environment. The frictional behavior depends on the relative hardness of the ball-on-disk materials. The increased α-Al_2O_3 and γ-Al_2O_3 phases with an increase in the current intensity were found to reduce the friction.

1. Introduction

Arthritis and related conditions like rheumatism are the leading cause of disability in the United States affecting nearly 43 million Americans and it is estimated that 60 million people will be affected by the year 2020 [1]. Artificial joint replacements are an answer to such a disability. With more people falling victim to such ailments, a need has been developed to discover newer and better biomaterials [2]. Plastic-on-metal and metal-on-metal are the traditional bearing couples that are being used for generations. But in the long run they have not proved to be effective [3]. The metal-on-metal couple triggers inflammation and formation of ions in the body [4,5] whereas the plastic-on-metal produces wear debris which causes osteolysis [4]. Both of these require corrective surgeries only after a few years of service. Ceramics on the other hand are biocompatible, hard and extremely corrosion and wear resistant [6]. Thus a ceramic-on-ceramic joint will have lower wear and tear thus lower formation of wear debris [7], providing many years of service. And in younger and active patients, coated implants are recommended [8]. Among all the ceramics, alumina and zirconia or their combination are the best choice because of their biocompatibility, low friction and easy availability. In this paper, we focus on alumina, a chemically inert and a highly wear resistant ceramic. Alumina coatings deposited by traditional methods such as vacuum deposition or plasma spray have either insufficient adhesion or cause the Al-based materials to overheat [9], while the MAO process gives strong adhesion, thick coatings and improves the wear and the corrosion resistance [10,11]. MAO coatings have a broad range of load bearing capacities and can be used for applications where light weight and corrosion resistance are required [12]. The present paper discusses the tribological characteristics, friction and wear of MAO alumina coatings in order to determine the feasibility of alumina as an implant material.

2. Materials and methods

2.1. Materials

Samples: Rectangular samples of aluminum alloy Al-7039T6 were used as substrates; the nominal composition of this alloy is 0.068% Si, 0.139% Fe, 0.081% Cu, 0.266% Mn, 2.25% Mg, 0.198% Cr, 4.12% Zn, 0.012% Ti and Al balance. Using a100 kW microarc oxidation equipment, consisting of a stainless steel container, an ac power supply, cooling and stirring systems; ceramic coatings were deposited on the Al alloy samples in a weak alkaline electrolyte. The Al alloy specimen was the anode and the wall of the stainless steel container was the cathode.

Coatings were produced at different current densities for 150 min. The basic layers obtained in the microarc oxidation method are shown in Fig. 1. The topmost layer is the external layer, composed of γ-Al_2O_3 [15] which makes the layer less hard followed by a dense internal region, consisting of α-Al_2O_3, which makes the

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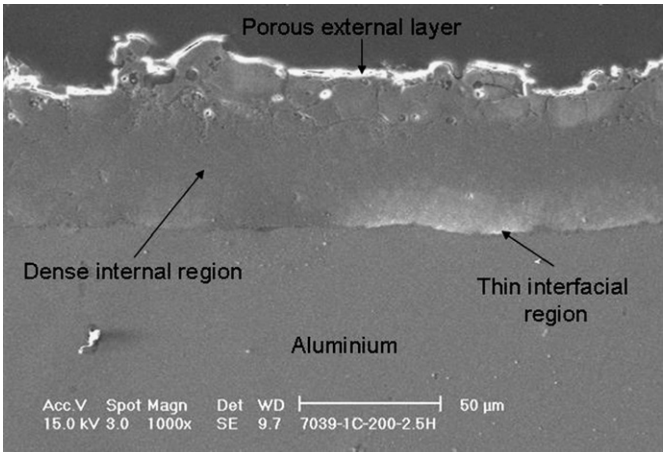

Fig. 1. Microstructure of the different layers obtained in the alumina coating.

Table 1
Coating thickness, micro-hardness, microstructure and surface roughness of the MAO coatings

Sample	Coating thickness (µm)	Scratch force (N)	Micro-structure	Surface roughness (µm)
0.100 A/cm^2, 2.5 h	96.20	0.735	Aluminium, Mullite, δ-Al_2O_3, Al_2O_3	7.53
0.125 A/cm^2, 2.5 h	128.0	0.760	Aluminium, Mullite, γ-Al_2O_3	8.59
0.150 A/cm^2, 2.5 h	142.0	0.845	Mullite, γ-Al_2O_3, α-Al_2O_3, Al_2O_3	9.59

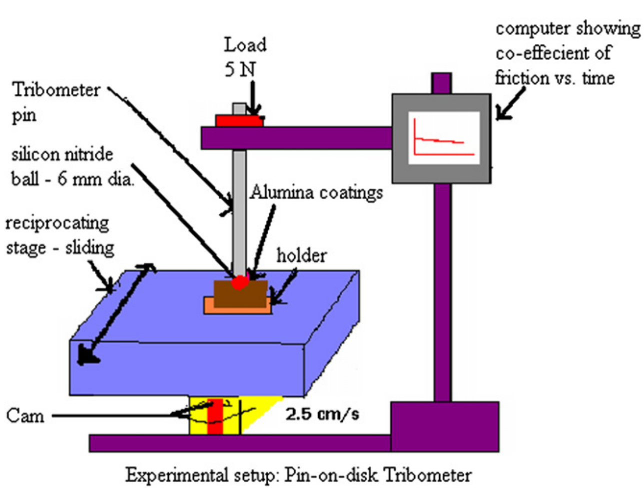

Fig. 2. Experimental setup.

Table 2
Summary of the friction co-efficients for the MAO coatings

Sample	Start	Min	Max	Mean	Std. dev
0.100 A/cm^2, 2.5 h	0.349	0.158	0.371	0.192	0.029
0.125 A/cm^2, 2.5 h	0.189	0.067	0.246	0.175	0.019
0.150 A/cm^2, 2.5 h	0.332	0.117	0.243	0.167	0.018

layer hard and less permeable [13] and finally the interfacial layer which is in between the coating and the aluminium substrate. The coatings generated using AC MAO show good adhesion to the substrate [18].

In this paper, we will be comparing three samples obtained at 0.100, 0.125 and 0.150 A/cm^2 current densities oxidized for 150 min [14]. The characteristics of the coatings were analyzed using an

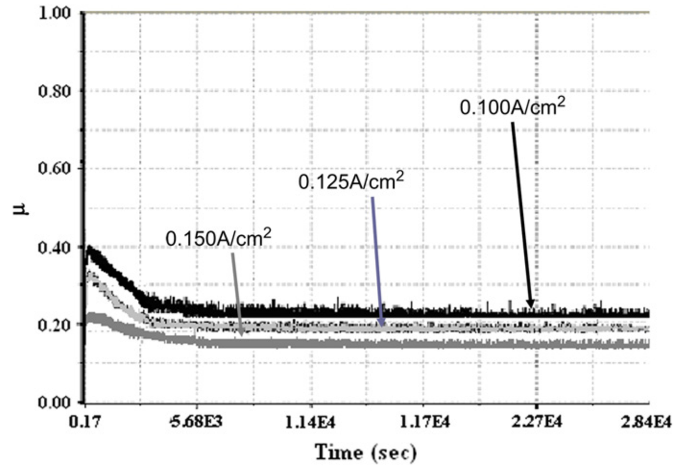

Fig. 3. The coefficient of friction vs. time for the three MAO coatings.

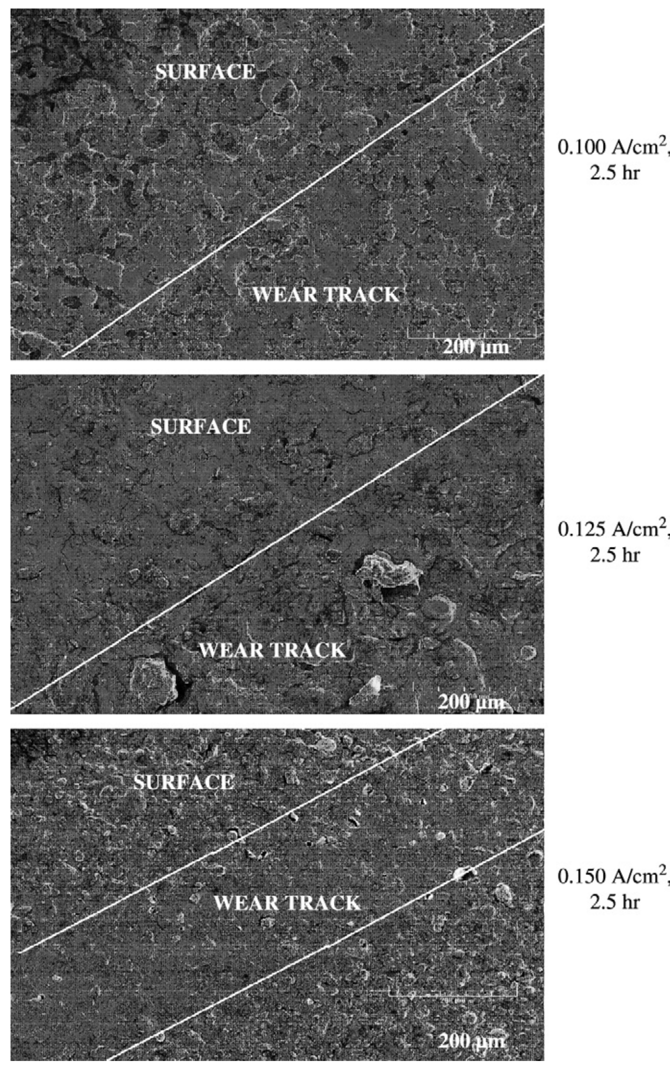

Fig. 4. The wear track–surface interface for all the three MAO coatings.

eddy current coating thickness measurement gauge (Fisher, Germany), scratch test modified on a scratch-on-disk tribometer, Scanning Electron microscope and Veeco Dektak Surface Profilometer (Sloan Technology) respectively and the results are listed in Table 1.