Coatings for Biomedical and Healthcare Applications
Room Pacific C - Session D2-TuM

Medical Devices: Bio-Tribo-Corrosion, Diagnostics, 3D Printing

Moderators: Steve Bull, Newcastle University, UK, **Hamdy Ibrahim**, University of Tennessee at Chattanooga, USA, **Margaret Stack**, University of Strathclyde, UK

8:00am **D2-TuM-1 Characterization of Hydroxyapatite Coatings Produced by Pulsed-laser Deposition on Ti_6Al_4V Substrates Fabricated by Electron Beam Melting**, ***Octavio Andrés González-Estrada (agonzale@uis.edu.co)***, *R. Ospina, A. Pertuz,* Universidad Industrial de Santander, Colombia

Additive manufacturing is a disruptive technology that has changed the design of bone implants for clinical applications. In this work, the effect of the deposition energy parameter on the mechanical properties and surface microscopy of Ti6Al4V alloy substrates manufactured by electron beam melting (EBM) and coated with hydroxyapatite (HA) deposited by the pulsed laser technique (PLD) was investigated. The average hardness and microhardness values were obtained under microindentation and indentation tests following the standard practice for instrumented indentation ASTM E384-17, as well as, scratch tests for adhesion behavior. The morphology and chemistry of the substrate coating were evaluated using scanning electron microscopy (SEM) and X-ray photoelectron spectroscopy (XPS), resulting in average values of HA particle formation size of the coating. Variables that reflect the incidence of deposition parameters in relation to the mechanical and micrographic properties of the HA coating were assessed.

8:20am **D2-TuM-2 Preclinical in Vitro and in Vivo Assessment of High-Strength and Corrosion-Controlled Magnesium-Based Bone Implants**, *C. Billings,* University of Tennessee Knoxville, USA*; M. Abdalla,* University of Illinois - Chicago, USA*; D. Anderson,* University of Tennessee Knoxville, USA*;* ***Hamdy Ibrahim (HAMDY-IBRAHIM@UTC.EDU)***, University of Tennessee at Chattanooga, USA

Magnesium is a lightweight metal that is naturally present in the human body with a biodegradable nature in aqueous mediums. These properties make magnesium an attractive material for its use in various biomedical applications when the material is not recommended to stay permanently in the body, such as bone implants. Some of the main challenges that hinder the use of magnesium for bone fracture repair are its limited mechanical strength and fast corrosion rates which results in peer biomechanical performance in the body. To this end, we have developed both a biocompatible magnesium alloy (Mg-Zn-Ca-Mn-based alloy) and a fabrication method (heat treatment and coating) that deliver a high-strength and corrosion-tailored material that can provide the needed stability during the healing period for bone implant applications, and subsequently degrade until vanished completely after the healing of tissues. The created coating consists of two layers; a first ceramic layer (10 µm thick) made by using the micro arc oxidation (MAO) process followed by a thinner layer (1-2 µm thick) of Ca/P-based ceramics created by using the sol-gel technique. The sol-gel coating resulted in a significant reduction in corrosion rate, as low as 1.1 µm/year which is 27 times less than that for the MAO-coated alloy alone. In vitro and in vivo assessments of our magnesium alloy and fabrication method showed high levels of biocompatibility in terms of cytotoxicity, degradation rates, and fracture healing. For instance, our animal studies, using New Zealand white rabbit utilizing a lateral femoral condyle model, showed no negative effects on bone formation, and no evidence of a strong or persistent inflammatory reaction. The results of this study show that it is possible to produce biocompatible magnesium-based implants with stronger and more corrosion-controlled properties.

8:40am **D2-TuM-3 Understanding Tribological Contact in Biomedical Applications; The Role of Surface Film Formation and Its Correlation With Friction and Wear**, ***Mark Rainforth (m.rainforth@sheffield.ac.uk)***, The University of Sheffield, UK*; R. Namus, J. Qi, J. Nutter,* University of Sheffield, UK **INVITED**

The impact of tribology (friction and wear) on the economy is a substantial 5-8% of GDP and plays a central role in everyday life, for example, in transport, manufacturing, process engineering and medical devices.The tribological performance of a component is a strong function of the interaction between the component surface and the operating environment, and how the surface changes in response to the contact stresses. In many cases, the tribo environment activates electrochemical reactions, which is particularly true in orthopaedic components. It is these dynamic changes that determine the success or failure of the component. In many cases, distinct surface structures are generated by the sliding contact. Of these, the formation of tribofilms is perhaps the most important. Evidence is mounting that tribofilms play a crucial role in the success of components, particularly in the articulating surfaces in orthopaedic components. The conditions under which tribofilms form is still far from clear. In this work a detailed analysis of the tribocorrosion behaviour of Ti-6Al-4V and CoCrMo alloys was undertaken under a range of electrochemical and load conditions in order to determine the conditions under which a tribofilm forms and the role that the tribofilm plays. The structure of the tribofilm is considered in detail, down to the atomic scale. High resolution transmission(scanning) electron microscopy and electron energy loss spectroscopy have been used to characterise the structure and chemical composition of the tribofilm. A detailed, quantitative, analysis of surface deformation was also undertaken, in particular, the geometrically necessary dislocation (GND) density was quantified using precession electron diffraction (PET). For the first time, graphitic and onion-like carbon structures were found. It has been clearly shown that the presence of carbon nanostructures in the tribocorrosion process and the formation of the tribofilm leads to an improved tribocorrosion behaviour of the system, in particular a reduction in wear and friction. A clear correlation between applied potential and tribofilm formation has been established, with tribofilms forming on a passive surface, but not on a metal surface where an oxide is not present. Interestingly, there appears to be a correlation between the extent of surface deformation with the presence of a tribofilm and the surface potential; anodic conditions result in much greater surface deformation than cathodic conditions. However, there was no correlation between the surface deformation and the wear rate. The implications for these observations on the wear performance of these materials is discussed.

9:20am **D2-TuM-5 Corrosion Resistance of Cerium Oxynitride Thin Films for Use in Implants and Prothesis**, *G. Numpaque Rojas,* ***Brian Felipe Mendez Bazurto (bfmendezb@unal.edu.co)***, *G. Cubillos Gonzalez,* Universidad Nacional de Colombia

Due to its chemical properties and high corrosion resistance, the cerium oxide has been widely used in aeronautical and naval industry as coating of aluminium alloys [1, 2]. The CeO is deposited mainly by suspended techniques, clean high vacuum techniques deposit of cerium oxide has not been studied since being a pyrophoric solid, and the films obtained are porous and easily delaminated. In this work, we determine the conditions of pressure, temperature and nitrogen flow to deposit homogeneous films on stainless steel AISI 316L surgical grade and corrosion resistance cerium oxynitride was evaluated. CeOxNy/ZrOxNy coatings were obtained from a 4 in. ×1/4 in. Zr-Ce (99.9%) target (Stanford Advanced Materials). RF reactive sputtering technique, in atmosphere of N2/O2, with a flow ratio ΦN2/ΦO2 of 20 was used. The structural analysis carried out through X-ray diffraction (XRD) showed that the CeOxNy/ZrOxNy coatings had a cubic polycrystalline structures preferencial growth for CeOxNy, while ZrOxNy is amorphous. The SEM analysis evidenced that the films grew with homogeneous morphology and exhibited a columnar growth. Corrosion resistance evaluated from the potentiodynamic polarization curves in Hank's solution [3], showed that the coating increases the corrosion resistance of steel by two orders of magnitude. CeOxNy/ZrOxNy coatings deposited on surgical grade stainless steel could be a promising candidate to be used in osteosynthesis processes.

9:40am **D2-TuM-6 Porous Ti Under Tribocorrosion Solicitations: Some Positive Feedback and Some Scientific Benefits**, *A. Gomes Costa,* CMEMS-Minho University, Portugal*; F. Viana,* FEUP, Portugal*; L. Rocha,* DTX, Portugal*; F. Toptan,* DMSE, İYTE, Turkey*;* ***Jean Geringer (geringer@emse.fr)***, Mines Saint-Etienne, France

About biomaterials dedicated to bone substitutes, some candidates are promising like Hydroxyapatites, cell growth boosters, etc. One candidate is titanium foam for two reasons: promoting vascularization thanks to 3D structure and bone cells attachments and growth. Some concerns are on tribocorrosion resistance. This work is dealing with titanium foam (void 50% approx.) under tribocorrosion solicitations in physiological environment, i.e. bovine serum. The consequences of the micro-displacements (+- 40 µm sinusoidal displacement) under normal loads from 22.5N till 200N were analyzed through the materials integrity. Moreover the tribological analysis was investigated and the Master curve, A (dissipated energy over the total dissipated energy) vs. 1st OCP (Open

Circuit Potential) drop was used to manage the influence with normal load and displacement amplitude. The results are in accordance with stick/slip phenomenon. A fretting map was illustrated and the fretting regimes were highlighted. The A-1st OCP curve is in accordance with the type of degradations, i.e. macroscopic wear.

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