

Coatings for Biomedical and Healthcare Applications Room California - Session D1-1

Surface Coatings and Surface Modifications in Biological Environments

Moderators: Kerstin Thorwarth, Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland, Mathew T. Mathew, University of Illinois College of Medicine at Rockford and Rush University Medical Center, USA

10:00am **D1-1-1 Highly Porous Scaffolds on TNZT Alloys for Bone Implant Applications, Samir Aouadi, E Blackert, S Murguia, M Kramer, S Bakkar, M Young, University of North Texas, USA**

TNZT alloys with compositions of Ti-35Nb-7Zr-5Ta are materials that are more biocompatible than the more widely used Ti-6Al-4V alloy since each of its constituent elements is biocompatible. In addition, it has the lowest Young's modulus of all the titanium-based alloys created so far (50-60 GPa). This property allows for a greater transfer of functional loads, which ultimately leads to bone growth stimulation. TNZT alloys were produced by arc melting of pure elements and were forged into rods. Oxide nano-scaffolds were grown on TNZT using the hydrothermal method to investigate the potential of these nanostructured surfaces to improve osseointegration. The alloys with and without nano-scaffolds were characterized using top-view and cross-sectional scanning electron microscopy equipped with an energy dispersive x-ray spectrometer to investigate the structure, morphology and chemistry of the resulting nanostructures. Finally, the formation of hydroxyapatite on the modified surfaces was investigated upon immersion in simulated body fluid (SBF).

10:20am **D1-1-2 Improving Cellular Proliferation on the Ti-6Al-4V Alloy by the Formation of Crystalline Nanotubes of Titanium Oxide, Itzel Pamela Torres-Avila, Instituto Politecnico Nacional-Upibi, Mexico; E Hernández-Sánchez, J Castrejón-Flores, Instituto politécnico Nacional-UPIBI, Mexico; J Velazquez, Instituto Politécnico Nacional-ESIQIE, Mexico; R Carrera-Espinoza, Universidad de las Américas Puebla, Mexico; U Figueroa-López, Tecnológico de Monterrey, Campus Estado de México, Mexico**

This work is about the formation of crystalline nanotubes of titanium oxide at the surface of the Ti-6Al-4V alloy and the evaluation of their effect on the cellular proliferation. The formation of nanotubes was performed by the anodic oxidation technique. The work potential was established in 60 V. The anodizing process was performed at times of 10, 20, 30, 40 50 and 60 min, in order to evaluate the effect of treatment time on the characteristics of the nanotubes and thus, on the cellular proliferation. A mixture of ethylene glycol, water and ammonium fluoride was used as electrolytic fluid. Scanning electron microscopy (SEM) and X ray diffraction (XRD) were applied to determine the morphology and the crystalline nature of the nanotubes. SEM examination showed a well-defined matrix of nanotubes of titanium oxide with crystalline structure and diameter in the range of 60 to 80 nm. The XRD patterns showed more and more defined picks as the treatment time was increased. The results also revealed a clear influence of the treatment time on the structure of the titanium oxide nanotubes, especially on the adherence to the substrate, where the best adherence was observed with 60 min of treatment. The cellular assays showed that the cells attach to the nanotubes and proliferated.

10:40am **D1-1-3 Effects of Nb and Ti on the Corrosion and Biocompatibility Behavior of Zr-based and Fe-based Thin Film Metallic Glasses, Jhong-Bo Wang, Y Yang, National Taipei University of Technology, Taiwan; J Lee, Ming Chi University of Technology, Taiwan**

Recently, thin film metallic glasses (TFMGs) have drawn lots of attention from researchers due to their potential applications in the biomedical fields. In this work, a series of Zr-based and Fe-based TFMGs were prepared by a pulsed DC and RF magnetron co-sputtering system. TFMGs were deposited on 316L stainless steel and P-type (100) Si wafers. For the Zr-based and Fe-based TFMG, Nb and Ti elements were added, respectively. The amorphous structures of coatings were determined by a glancing angle X-ray diffractometer. The surface and cross sectional morphologies of thin films were examined by a scanning electron microscopy (SEM). The surface roughness of thin films was explored by an atomic force microscopy (AFM). A nanoindenter, HRC-DB adhesion test were used to evaluate the hardness and adhesion properties of thin films, respectively. The bio-corrosion properties were tested by an electrochemical polarization measurements. The biocompatibility of TFMGs was examined using MG63 cell and the MTS

assay. Effects of Nb and Ti addition on the corrosion resistance and biocompatibility behavior of TFMGs were discussed.

11:00am **D1-1-4 Tribological Behavior of Nanotubes Grown on Ti-35Nb Alloy by Anodization, A Luz, UFPR, Brazil; Carlos Lepienski, Universidade Tecnológica Federal do Paraná, Brazil; C Siqueira, Universidade Federal do Paraná, Brazil; G Souza, Universidade Estadual de Ponta Grossa, Brazil; N Kuromoto, Universidade Federal do Paraná, Brazil**

β -type titanium alloys have been proposed to replace the Ti-6Al-4V alloy due to the V and Al toxicity for long term use. Such β alloys with Nb, Mo, Zr, Sn or Ta additions are considered nontoxic, presenting lower elastic modulus than other conventional biomaterials. However, the tribological behavior of Ti and its alloys are unsatisfactory, featured by high wear rates and friction coefficients that limit applications in the biomedical area. Surface treatments can be employed to improve the surface properties while maintaining the bulk properties. Nanotubes can be produced through anodization, composed of oxides with elements from the substrate, such as TiO₂. Structure and morphology of nanotubes grown on Ti and its alloys can improve the surface biocompatibility, wettability and corrosion resistance as compared to untreated materials. However, there are few studies on the tribological properties of these films. The purpose of this study was to investigate the friction coefficient and wear rate of nanotubes grown on Ti-35Nb alloy, using a linear reciprocating tribometer. Results were compared with Ti and polished Ti-35Nb alloy. Hardness and elastic modulus of the substrates were measured through instrumented indentation. The produced coatings were also characterized by X-ray diffraction, scanning electron microscopy and metallographic analysis with optical microscopy. Nanotube layers were grown in an electrolyte containing 1 M H₃PO₄ + 0.8 wt.% NH₄F, at 20 V for 160 minutes. The nanotubes were annealed at 530 °C for 3 h. The Ti-35Nb alloy comprises α and β phases. The Ti-35Nb alloy presented higher hardness (3.7 GPa) and lower elastic modulus (96 GPa) than the pure Ti, a consequence of the β phase-containing microstructure. The nanotubes exhibited random diameters and approximately 2 μ m thick. The crystal structure of the nanotube layers was a mixture of TiO₂ and Nb₂O₅ oxides. Friction coefficient of the nanotube layers was in the 1.0-1.1 range, lower than that of the polished Ti-35Nb (1.3) and the Ti surfaces. Likewise, wear rate of these coatings was (0.06 \pm 0.01).10⁻³ mm³/N.m, which was much lower than the value obtained for Ti-35Nb alloy [(1.66 \pm 0.13).10⁻³ mm³/N.m]. The wear mechanisms were adhesive and abrasive on Ti and Ti-35Nb alloy. However, the surface coated by the nanotube layers disclosed nor adhesive neither abrasive characteristics, in contrast to the reference surfaces. The low wear rates suggested a good adhesion between layer and substrate.

11:20am **D1-1-5 Designing Hydrogels to Enhance Biomedical Implant Performance, Stephanie Bryant, University of Colorado, Boulder, USA, United States of America**

INVITED

The foreign body response (FBR) occurs ubiquitously to nearly all implanted non-biological materials and is characterized by fibrous encapsulation. The primary orchestrators of the FBR are macrophages, but efforts to control macrophage phenotype and subsequently the FBR have been challenging. This observation is in part due to the fact that macrophages have highly disparate functions ranging from inflammation to wound healing. It is well accepted that macrophages sense a biomaterial through the adsorbed proteins, but the nature by which adsorbed proteins mediate macrophage phenotype and ultimately the FBR remains poorly understood. While traditional efforts focused on creating 'bioinert' biomaterials as a means to prevent protein adsorption, recent evidence demonstrates that even hydrophilic materials readily adsorb proteins and elicit a FBR. This has led to a shift from 'bioinert' to 'bioactive' materials as means to control macrophages and subsequently the FBR. To this end, our group designs synthetic-based hydrogels to which bioactive molecules (e.g., extracellular matrix (ECM) analogs, small molecules, etc.) are introduced in a highly controllable and tunable manner to create tissue-like mimetic materials. We use poly(ethylene glycol) (PEG) hydrogels as the base structural component to control the bulk properties. Proteins, glycosaminoglycans, peptides, or other small molecules that are functionalized with polymerizable groups are then tethered into the PEG. Our group has characterized the FBR to PEG hydrogels, in the absence of any bioactive signals, and demonstrated through *in vitro* and *in vivo* experiments, a robust FBR with macrophage recruitment, macrophage activation, and the formation of a fibrous capsule. Incorporating bioactivity, as simply as, a cell adhesion peptide sequence, is sufficient to attenuate the response, but not abrogate the response. Using knockout mice models, we have identified that the initial inflammatory response mediates the long-term fibrotic response suggesting that targeting the early stages of the FBR may be

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critical to the long-term prevention of the FBR. In addition, we have identified that prostaglandin E2, a molecule that is secreted by stem cells to control inflammation, can significantly reduce the inflammatory macrophage phenotype and the associated FBR *in vivo*. Current efforts are focused on creating biomimetic and anti-inflammatory hydrogels as a means to dynamically control macrophage phenotype at an implant surface and improve the long-term performance of implantable biomaterials.

12:00pm **D1-1-7 Fabrication and Properties of Ca, P Containing Coating on Magnesium Alloy by Micro-arc Oxidation**, *Hui Tang*, University of Electronic Science and Technology of China, China

As a novel metallic bio-absorbable implant material, magnesium alloy has drawn tremendous interest recently. However, relatively poor corrosion resistance in an environment of physiological fluids restricts their broad applications. In this study, Ca, and P containing coating were prepared on the surface of AZ31 magnesium alloy by micro-arc oxidation. The morphologies, composition, wettability, mechanical properties and corrosion resistance of the coatings were investigated. The corrosion mechanism was studied by long-term immersion in Hank's solution. And the formation mechanism of hydroxyapatite in SBF solution was also studied by combining the ICP and SEM. The results demonstrate that the Ca, P coating could improve the corrosion resistance of magnesium alloy in Hank's solution, and increase the bioactive of the magnesium alloy. The morphologies, composition, wettability and corrosion resistance could be controlled by the composition of the electrolyte and power parameters.

Coatings for Biomedical and Healthcare Applications Room California - Session D1-2

Surface Coatings and Surface Modifications in Biological Environments

Moderators: Kerstin Thorwarth, Empa, Swiss Federal Laboratories for Materials Science and Technology, Switzerland, Mathew T. Mathew, University of Illinois College of Medicine at Rockford and Rush University Medical Center, USA

1:30pm D1-2-1 Optimisation of Antimicrobial Silver Nanocomposite Coatings on Orthopaedic Grade Cobalt Chromium Alloys and the Related Simulator Analyses in Knee Surgery, Liuquan Yang, Wallwork Cambridge Ltd, UK; *L Richards,* MatOrtho Limited, UK; *J Shelton,* Queen Mary University of London, UK; *H Hothi,* University College London, UK; *S Collins,* MatOrtho Limited, UK; *J Housden,* Wallwork Cambridge Ltd, UK; *A Hart,* University College London, UK; *L Espitalier,* Wallwork Cambridge Ltd, UK

Hard wearing PVD silver nanocomposite coating has shown the antimicrobial effect in previous research and a good ion barrier for the release of heavy metal ions from the conventional orthopaedic grade cobalt chromium (CoCr) alloy. Therefore, such a coating family may be considered as a promising candidate in orthopaedic applications with bearing surfaces and in particular may lower the risk of post-operation infection. The control of silver release and the overall tribological friction/wear performances are critical for the safety and longevity of the orthopaedic implant research. This study focuses on optimisation of four the electron beam physical vapour deposition (EBPVD) coatings deposited on the medial rotation knee (MRK™) surface with different levels of silver contents in the coating structure. The overall coating assessments are carried out on simulator testing in vitro for antimicrobial effectiveness, i.e., silver ion and particle release, and wear characterisations against ultra-high molecular weight polyethylene (UHMWPE). The proposed optimised coating structure will be subject to biocompatibility tests and clinical trials.

1:50pm D1-2-2 Structure and Properties of Novel Hydrophobic Cr-Ag Antibacterial Coatings Deposited by Closed-field Unbalanced Magnetron Sputtering, MohammadSharear Kabir, University of New South Wales, Australia; *A Karami,* University of Adelaide, Australia; *P Munroe,* University of New South Wales, Australia; *Z Zhou,* City University of Hong Kong, Hong Kong; *Z Xie,* University of Adelaide, Australia

Antibacterial coatings are defined as surface coatings that can repel or resist the attachment of bacteria by exhibiting bactericidal or anti-biofouling effects. They are emerging as a primary component in surface applications to mitigate problems related to bacterial pathogens. In this study, we have investigated the structure and properties of Ag-doped Cr coatings. These coatings were deposited by closed-field unbalanced magnetron sputtering method using pure (99.99 %) Cr and Ag targets. The structure and mechanical properties of the coatings were investigated using X-ray diffraction (XRD), transmission electron microscopy (TEM), focused ion beam microscopy (FIB) as well as nanoindentation. XRD analysis revealed Cr (110) as the dominant texture with the emergence of Ag (111) as the Ag content increases. TEM analysis revealed that the coatings were composed of distinct columnar grains several hundred nanometres in length. Furthermore, the coatings exhibited a hardness of around ~8 GPa with significant abrasion resistance and hydrophobic behaviour with a contact angle of ~114°. Ongoing work is investigating the behaviour of these coatings under conditions of bacterial colonization.

2:10pm D1-2-3 Thin Film Metallic Glass : A Lubricated Coating on Medical Needle for Reducing Fracture Toughness and Damage of Phantom Materials, Berhane Gebru, J Chu, C Yu, National Taiwan University of Science and Technology (NTUST), Taiwan

A two successive insertion of bare and thin film metallic glass (TFMG) coated needles was used to measure the fracture toughness of polyurethane rubber block and porcine skin. We found that the TFMG coating reduced the fracture toughness of polyurethane rubber block and porcine tissue by more than 10 % compared to a bare needle. In both testing materials, a reduction in the cutting and frictional force is observed for insertion of TFMG-coated needle. The reduced cutting and frictional force can be ascribed to the low coefficient of friction (COF) of TFMG measured by nano-scratch tests. In addition, compared with bare needle, the crack area created on polyurethane rubber and porcine tissue for insertion of TFMG-coated needle is noticeably reduced. The results imply

that by employing TFMG coating on the medical needle is capable of reducing the trauma of human tissue.

2:30pm D1-2-4 Biocompatibility and Antimicrobial Performance of a Durable Super-hydrophobic Surface Modified Stainless Steel, Cheng-Wei Lin, Feng Chia University; Central Taiwan University of Science and Technology, Taiwan; *C Chou,* Taichung Veterans General Hospital; National Yang-Ming University, Taiwan; *C Chung,* Central Taiwan University of Science and Technology, Taiwan; *J He,* Feng Chia University, Taiwan

For orthodontic application, a durable super-hydrophobic surface has been developed on AISI 304 stainless steel by sandblasting, electrochemical treatment and fluorocarbon plasma polymerization (SEP). The hybrid surface possesses nano/micro coexisting structure and present super-hydrophobicity (water contact angle 154°) and good abrasion durability. In this study, the *in vitro* tests for cell compatibility and antimicrobial behavior were performed by using fibroblast cell culture and bacterial cell culture, respectively.

The results reveal that the obtained hybrid surface exhibit better cell proliferation in comparison with the bare AISI 304 stainless steel (SS). In the antimicrobial test, the SEP surface also exhibit a comparatively lower level of bacterial adhesion than SS. These results suggest that the hybrid SEP treated AISI 304 stainless steel present good cell compatibility and antimicrobial performance, which are essential for orthodontic application.

2:50pm D1-2-5 Immobilization of Carboxylic Acid Groups on Polymeric Substrates by Plasma-enhanced Chemical Vapor or Atmospheric Pressure Plasma Deposition of Acetic Acid, Wei-Yu Chen, A Matthews, University of Manchester, UK; *F Jones,* University of Sheffield, UK; *K Chen,* Tatung University, Taiwan

Low-pressure plasma-enhanced chemical vapor deposition (PECVD) is a process that activates the precursor in the plasma state to deposit films on the surface. Introducing carboxylic acid functional groups via PECVD has been widely applied in various applications, such as the enhancement of interfacial adhesion between fillers and matrices in composite materials, molecular grafting for biosensors and biocompatibility improvement. To develop a compatible surface for cell adhesion, polymeric substrates, poly (lactic-co-glycolic acid) (PLGA) and polyethylene terephthalate (PET), were modified by a low-pressure acetic acid plasma to improve surface hydrophilicity and biocompatibility. The acetic acid plasma deposited film maintained stability on a hydrophilic surface for long-term aging and possessed good biocompatibility. If the acetic acid film can be deposited by process using atmospheric pressure plasma (APP), a more rapid, economic and power-saving method can be achieved. In this study, a remote APP system using a bespoke Pyrex APP chamber was utilized to deposit acetic acid film onto the surfaces of polymeric substrates. The wettability, stability of hydrophilicity and surface elemental composition of the APP-deposited film will be reported and compared with that prepared via low-pressure acetic acid plasma.

3:10pm D1-2-6 Coatings Deposition by RF Magnetron Sputtering of Loosely Packed Hydroxyapatite Powder Target, Laurynas Lukosevicius, The University of Manchester, UK; *S Mráz, J Schneider,* RWTH Aachen University, Germany; *A Matthews,* The University of Manchester, UK

It is well known that hydroxyapatite (HA), which is the major mineral compound of bone tissue, promotes orthopedic implants osteointegration when applied in a mixture or composite material compound. HA target preparation can be difficult and target cracking can occur. Therefore, many different target preparation techniques such as sintering, mixing HA with additional materials, HA plasma spraying copper discs prior the deposition or directly sputtering from the powder have been employed during previous research. Also, the deposition of HA is complicated due to the target and grown film decomposition as well as low bonding strength of the coating to the substrate.

In this study, amorphous HA coatings were deposited on Titanium, Magnesium and Silicon substrates from three different loosely packed powder target electrodes arrangements by radio frequency magnetron sputtering in an argon environment pressure of 5–50 mTorr and magnetron power of 30–381 W (1.5–6 W/cm²). Deposition from solid and powder target materials has been evaluated and compared. Furthermore, the influence of the deposition parameters on the coating phase and elemental composition has been investigated.

The Ca/P ratio has been evaluated by means of EDS and XPS. FTIR and Raman analysis revealed that deposited coatings contain a typical calcium phosphate structure. The analysis showed that coatings of a multiphasic mixture containing HA, TCP, pyrophosphate and CaO have been formed.

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Furthermore, pyrophosphate was the major compound of the coating deposited at 50 mTorr process pressure. Heat treatment of the HA and titanium composites at 550 °C in air medium led to the crystallization of the coating.

3:30pm **D1-2-7 Advanced Medical Biosensing Systems with Soft/Stretchable Materials and Assemblies**, *J Rogers, Roozbeh Ghaffari*, Northwestern University, USA

INVITED

Unusual classes of electronics and electrochemical sensors enabled by recent advances in materials science and mechanics have been designed with 'skin-like' physical properties. These systems are highly conformal and wearable by virtue of their soft mechanics compared to conventional packaged electronics and sensors. In this talk, we present an overview of recent advances in novel materials, mechanics and designs for emerging classes of fully-integrated soft bio-electronics. These devices incorporate microfluidics and microfabricated arrays of sensors configured in ultrathin, stretchable formats for monitoring of hydration and (electro-)physiology. Quantitative analyses of strain distributions and electronics performances under mechanical stress highlight the utility of these advanced medical systems in the clinical and remote environments. We will conclude with representative examples of epidermal systems being tested in clinical studies and sports field trials.

4:10pm **D1-2-9 Cyclic Voltammetry Study of Electrolytic Plasma Processing of Porous Ti**, *M Shbeh*, University of Sheffield, UK; **Aleksey Yerokhin**, University of Manchester, UK; *R Goodall*, University of Sheffield, UK

Titanium is one of the most commonly used materials for biomedical applications. However, there are two issues associated with the use of it, namely its bio-inertness and high elastic modulus compared to the elastic modulus of the natural bone. Both of these hurdles could potentially be overcome by introducing a number of pores in the structure of the Ti implant to match the properties of the bone as well as improve the mechanical integration between the bone and implant, and subsequently coating it with a biologically active ceramic coating to promote chemical integration. This study has investigated the utility of cyclic voltammetry to understand processes that occur during electrolytic plasma surface treatments of porous Ti parts with different amounts of porosity produced by Metal Injection Moulding. Anodic behaviour of the porous Ti substrates was studied in aqueous solutions of disodium hydrogen phosphate in the voltage range 0 to 500 V. The shapes of the cyclic voltammograms for the relatively dense samples were relatively steady and not sensitive to the change in the scan rate, with more distinctive peaks indicating occurrence of complex multi-electron transfer processes observed. In contrast, for more porous samples the voltammograms had hump-shaped start and less distinctive peaks. The treatment of porous samples with higher porosity and open pores resulted in much thicker surface oxide layers that penetrate through the inner structure of the samples forming a network of surface and subsurface coatings. The results are of potential benefit in producing surface engineered porous samples for biomedical applications which not only address the stress shielding problem, but also improve the chemical integration with the bone matrix.

4:30pm **D1-2-10 Corrosion and Degradation Behavior of dahp pre-treated PCL Composite Coatings on Pure Magnesium**, *Yuyun Yang*, Institute for Corrosion Science and Surface Technology, China; *K Zheng*, Institute of Biomaterials, Germany; *G Jin, X Cui*, Institute for Corrosion Science and Surface Technology, China; *S Virtanen*, Institute for Surface Science and Corrosion, Germany; *A Boccaccini*, Institute of Biomaterials, Germany

Application demands for magnesium have increased dramatically recently due to its favorable mechanical properties. However, the poor corrosion resistance of magnesium under corrosive environment strongly impedes numerous applications, particularly in the biomedical field. Numerous efforts have been made to improve the anticorrosion property of magnesium, such as increasing purity level, modifying composition, and altering the microstructure by heat treatments. Surface modification has been proved to be an efficient and cost-effective approach in enhancing corrosion resistance and degradation behavior of magnesium. Polymeric coatings are attracting increasing attention because of their pronounced protective effect on magnesium matrix. Polycaprolactone (PCL) has been employed in a series of composite coating systems developed in our group to control the dissolution of magnesium. However, the main weakness of polymeric coatings is the unsatisfied adhesion to the bulk matrix. Therefore, pretreatment of magnesium is required to enhance the interaction between the magnesium matrix and polymeric coatings. Diammonium hydrogen phosphate (DAHP) is commonly used to synthesis

hydroxyapatite in the hydrothermal method as an essential compound. In this study, DAHP was used to pre-treat magnesium under hydrothermal condition prior to PCL coating for enhancing the adhesion. It is also expected that DAHP pretreatment would facilitate the phosphate deposition and induce hydroxyapatite formation in further. In addition, nanoscaled bioactive glass particles (BGN) that were synthesized by a modified Stöber method were incorporated in the PCL coating to improve biological activities of the coated magnesium. The results showed that DAHP/PCL composite coatings offer magnesium significant protection against corrosion in comparison to the DAHP pre-coating and PCL composite coating. The DAHP/PCL composite coating shows great potential in improving corrosion resistance of magnesium for biomedical applications.

Coatings for Biomedical and Healthcare Applications Room Royal Palm 1-3 - Session D2

Bio-corrosion, Bio-tribology, and Bio-tribocorrosion

Moderators: Anna Igual Munoz, Universitat Politècnica de València UPV, Steve Bull, Newcastle University, Nuria Espallargas, Norwegian University of Science and Technology (NTNU)

8:00am **D2-1 Magnetic Abrasive Finishing of Additively Manufactured Components for Biomedical Applications**, *Hitomi Yamaguchi*, University of Florida, USA

INVITED

Additive manufacturing (AM), which produces components by depositing material, attracts attention in various fields, including medical device manufacturing. AM technologies have broken out of the traditional manufacturing paradigm, especially the manufacturing of complex components in small batches. Selective laser melting (SLM) is one of the most versatile AM processes, and it enables the production of components by binding powders. Components made using SLM have applications in a wide variety of industrial areas including aerospace, biomedical engineering, etc. However, the powder-consolidation mechanism in SLM influences the mechanical properties, surface morphology, and surface integrity (e.g., hardness and residual stress) of products and the corresponding product functions. Therefore, choice of post-SLM processes, such as heat treatment and surface finishing processes, plays an important role in minimizing these defects and maximizing the component performance. This presentation describes the effects of these defects on surface geometry (roughness), surface integrity (residual stress), tribocorrosive behavior, and wear characteristics of the SLM-produced 316L stainless steel samples. Tribocorrosive behavior and wear characteristics investigated with 0.9% NaCl solutions and SLM-produced 316L stainless steel samples will be introduced.

A manufacturing technology called *Magnetic Abrasive Finishing* (MAF) has been applied for surface finishing of the 316L stainless steel SLM-produced components. In MAF, ferrous particles are suspended by magnetic force and link together along the lines of magnetic flux in a magnetic field. The ferrous particle chains, connected by magnetic force, enable a flexible configuration. This unique behavior of the ferrous particles allows the application of the finishing operation not only to easily accessible surfaces but also to areas that are hard to reach by conventional mechanical techniques, such as freeform components (e.g., knee prostheses) and the interiors of capillary tubes (e.g., needles) and flexible tubes (e.g., catheter shafts). The ability of MAF to alter the surface roughness and change the residual stress from tensile to compressive was demonstrated. This presentation describes the fundamentals of MAF and its processing characteristics and mechanisms.

8:40am **D2-3 Investigating Some New Coatings to Improve the Modular Junction of Total Hip Prostheses**, *S Ehsani-Majd*, Mines Saint-Etienne, France; *V Fridrici*, Ecole centrale de Lyon, LTDS, France; *C Desrayaud*, Mines Saint-Etienne, France; *P Kapsa*, Ecole centrale de Lyon, LTDS, France; *A Boyer*, *Jean Geringer*, Mines Saint-Etienne, France

Hip replacement surgeries affect approximately 160'000 patients a year in France, 600'000 in the US and more than 1 million all over the world [1]. The main concern for both patients' health/quality of life and economical reasons is the lifetime of the implants. Due to mechanical restrictions hip stem, femoral neck and metal back are made of metallic alloys. The main aim of the current work is to study the Ti-6Al-4V—Ti-6Al-4V contact under fretting-corrosion conditions to understand the modular junction behavior and to improve it. To do so, an in-house made device was used and the experiments were performed in bovine serum. Open circuit potential data, coefficient of friction (COF) and total dissipated energy data were obtained from electrochemical and mechanical results. The second aim is to investigate/introduce new surface coatings (diamond-like carbon (DLC) coating) to improve the durability of the modular junction material. The hard surface on hard surface junctions are very difficult to control while assembling the prosthesis during the surgical operations. Therefore, to avoid this hard-on-hard contact, new surface coatings are under investigation. Finding the right coating will considerably promote the lifetime of the implants.

The initial results, corresponding to Ti-6Al-4V—Ti-6Al-4V contact, highlight both tribological behaviors. The friction coefficient, the dissipated energy and the related A ratio (dissipated energy over total dissipated energy) emphasize both tribological behaviors. The A-ratio lower than 0.2

represents partial slip phenomenon, while the A-ratio greater than 0.2 represents gross slip regime. The goal is to define a transition map between partial and gross slip regimes about this typical contact. Some results are in progress related to Ti-6Al-4V—Ti-6Al-4V/DLC coating. The results highlight that the DLC1—Ti-6Al-4V or DLC5—Ti-6Al-4V contacts result in better tribological properties as compared to Ti-6Al-4V—Ti-6Al-4V contacts, hopefully. Although all the experiments were cautiously investigated in the similar experimental conditions, controlling the stick or slip regimes is unreachable to get some statements about gross slip or partial slip regimes. The ongoing results seem to emphasize that DLC5 involves lower total wear volume than the one related to DLC1 coating. Some additional investigations are in progress in order to assess this first tendency.

References

[1] S. Kurtz, K. Ong, E. Lau, F. Mowat, M. Halpern, *J Bone Joint Surg Am.*, 89, 2007, 780-785.

Acknowledgements

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9:00am **D2-4 Tribological Coatings on Titanium Alloy (Ti6Al4V) for Orthopedic Applications**, *Kai-yuan Cheng*, University of Illinois at Chicago, USA; *N Pagan*, Auburn High School, USA; *M McNallan*, University of Illinois at Chicago, USA; *D Bijukumar*, *M Mathew*, University of Illinois College of Medicine, USA

Problems, including release of metal ions and inflammatory effects of wear debris, from Metal-on-Metal (MoM) artificial hip implants caused a major decline of this design in the market. After several recalls of commercial hip implant products, FDA issued warnings on MoM arthroplasty in 2010 and 2011. Since then, use of MoM implants in surgery have been rare. In this study, two proposed materials: solid state-carburized titanium and carbide-derived carbon(CDC), were synthesized on Ti6Al4V and examined for their corrosion, tribocorrosion, and biocompatibility properties. A preliminary conclusion is drawn for their use for this application.

In this study, there are four stages of experiments. **(1) synthesis:** Two carburization processes have been employed to produce specimens. For solid-carburized titanium, titanium alloy was buried in carburizing materials in a stainless steel crucible. The whole package was heated to 925°C in a box furnace for 48 hours. For CDC production, the titanium alloy pins were covered by graphite powder in an alumina crucible and heated to 1000°C for 20 hours under flowing argon gas. Then, the carburized samples were chlorinated at 700°C for 5 minutes. After all production processes, specimens were characterized by x-ray diffraction and Raman spectroscopy. **(2) corrosion:** The electrochemical cells for corrosion and tribocorrosion experiments were similar. They contain a counter electrode, a reference electrode and the sample is the working electrode in bovine calf serum (BCS, 30 g/L) solution. **(3) Tribocorrosion:** The experimental set-up is a combined hip simulator and electrochemical cell. The electrochemical tests were performed at open circuit potential and potentiostatic at -0.2 (V) condition. The experiment was performed for 3600 (s) with 16 (N) of applied normal force and 1(Hz) sliding frequency. **(4) Biocompatibility:** The biocompatibility test was performed with osteoblast cells (MG-63). Cell proliferation and cellular growth after 1, 3, and 6 days were analyzed using alamarBlue assay and Rhodamine phalloidine/DAPI staining.

Both treated samples experience more severe corrosion than untreated titanium alloy, which may result from crevice corrosion. However, results on both samples from the tribocorrosion experiments shows less wear-induced corrosion, and a lower wear rate and friction coefficient. Similar cell proliferation and confocal images indicate that biocompatibility is not affected by the treatment. The preliminary data shows that solid-carburized titanium and CDC have excellent potential for orthopedic applications. Further investigation of these materials is justified.

Tuesday Morning, April 24, 2018

Coatings for Biomedical and Healthcare Applications

Room Royal Palm 1-3 - Session D3

Medical Devices, Biosensors, and Biodegradation

Moderators: Jessica Jennings, University of Memphis, USA, Robin Pourzal, Rush University Medical Center

9:20am **D3-5 Osteochondral Tissue Regeneration into Porous PCL Scaffolds With and Without Chitosan Coatings of 98% or 80% Degree of Deacetylation**, *Caroline Hoemann*, George Mason University, USA; *J Guzmán-Morales, G Chen, J Rodriguez-Gonzales, E Jalali Dil, B Favis*, Ecole Polytechnique de Montreal, Canada; *J Henderson*, McGill University, Canada

INVITED

Polycaprolactone (PCL) is a bioplastic currently under development as a bone void filler. According to 3-dimensional *in vitro* osteogenesis assays, porous PCL scaffolds are hydrophobic and non-osteogenic, but the inner pore surfaces can become osteoconductive when coated with chitosan, a linear cationic polysaccharide composed of 98% glucosamine and 2% N-acetyl glucosamine (98% degree of deacetylation, DDA). In this study we tested the hypothesis that osteochondral bone regeneration is accelerated *in vivo* inside porous PCL scaffolds when the surfaces are coated with 80% or 98% DDA chitosan. Experiments were carried out under ARRIVE guidelines and institutional ethics-approved protocols. Sterile cylindrical PCL scaffolds with 155 μm average pore diameter were created, and coated or not with Layer-by-Layer polyelectrolytes followed by a surface coating of 98% DDA chitosan (PCL-98); half of the PCL-98 scaffolds were additionally coated with 80% DDA chitosan (PCL-80). New Zealand White rabbits (N=7) were submitted to small sequential knee arthrotomies to create two 3 mm diameter, 2 mm deep drill holes per trochlea, that were press-fit with PCL, PCL-80 or PCL-98 scaffolds just below the bone surface, or left to bleed as surgical controls. Distal femurs were collected at 1 day (N=1) or 6 weeks (N=6) post-operative and analyzed by micro-computed tomography and by non-decalcified plastic histology for repair tissue characteristics. At day 1, blood clot filled all PCL scaffold pores and drill-only defects. At 6 weeks, micro-CT measures and histological scores showed significant bone repair in drill-only defects compared to initial defects. Both PCL and PCL-98 scaffolds showed a minor and similar degree of bone ingrowth into the pores at the bottom of the scaffold, and PCL-80 scaffolds induced a slight bone resorption at the edges. PCL-98 scaffolds specifically promoted cartilage repair resurfacing, with around 80% repair tissue covering the scaffold surface compared to $\leq 20\%$ resurfacing of PCL-only and PCL-80. These data revealed that *in vitro* osteogenesis assays do not necessarily predict *in vivo* osteogenesis where complex factors (biofactor deposits, innate immune responses, multiple cell types, angiogenic and mechanical cues) all influence the regenerative response. This study generated new knowledge that PCL-only scaffolds have a similar capacity as PCL-98 scaffolds to allow vascular bone ingrowth in a trabecular bone environment, but have a significantly lower ability to support cartilage resurfacing of the scaffold in the synovial cavity environment. 98% DDA chitosan coatings improved chondroinductive properties of subchondral porous PCL scaffolds.

10:00am **D3-7 Vancomycin-Phosphatidylcholine Spray Coatings for Delivery of Antimicrobials from Implants**, *Rukhsana Awais, B Barr, R Gopalakrishnan, J Jennings*, University of Memphis, USA

Research on point-of-care coatings applied to implant materials has shown that manually applied coatings can be loaded with antibiotics for infection control and control of biofilm formation at the surface of implant. While release of antimicrobials has been shown to be effective at preventing infection *in vitro* and *in vivo*, manually-applied coatings are difficult to apply uniformly. In this study spray coatings were deposited on stainless steel coupons at flow rate of 45 and 60 liters per minute with a capillary of inner diameter of 25 micrometers using an aerosol spray device. The objective of the study was to compare the elution rate of the antibiotic deposited as a spray coating with the manually applied coating. Vancomycin mixed with phosphatidylcholine was mixed with deionized water to form a uniform mixture. Coatings loaded with water-insoluble dye Oil-Red O dye was also used to visually inspect the homogeneity of coatings. Control coatings consisted of vancomycin mixed with phosphatidylcholine which were then manually applied to the surface of coupons. An elution study in phosphate buffered saline was conducted for seven days and vancomycin concentrations were determined using HPLC. Evaluation of the results showed that there was a continuous release of the drug in PBS (phosphate buffered saline) over seven days compared to three day release from manually-applied coatings. A large burst of antibiotic was observed for manually-applied coatings, which was not present in spray-

applied coatings. Spray coatings had a uniform distribution over the entire surface of interest, compared to manually applied coatings with varying thickness of deposition observed visually. Coatings remained on the surface for seven days when elution studies were performed with the addition of dye Oil Red O to Phosphatidylcholine in the absence of antibiotic. Our studies suggest that a spray coating method for antibiotic release may be more effective in the application of local antibiotic therapy as prevention for infection in orthopedic surgery. In future studies, methods to increase the amount of coating will be sought, as well as design of a portable hand-held unit.

Coatings for Biomedical and Healthcare Applications Room Royal Palm 1-3 - Session D4

Biointerfaces: Improving the Cell Adhesion and Avoiding Bacteria Adhesion. What Kinds of Coatings Should be Used?

Moderators: Marcela Bilek, The University of Sydney, Margaret Stack, University of Strathclyde, Vincent Fridrici, Ecole Centrale de Lyon - LTDS

2:10pm **D4-3 Titanium Oxide Coatings to Improve Cell Adhesion and Differentiation**, *V Garcia-Perez, A Almaguer-Flores*, Universidad Nacional Autónoma de México, Mexico; *R Olivares-Navarrete*, Virginia Commonwealth University, USA; *A Fonseca-Garcia, Sandra Rodil*, Universidad Nacional Autónoma de México, Mexico

INVITED

Amorphous titanium oxide (aTiO₂) coatings were produced by magnetron sputtering using a Ti target and a reactive Ar/O₂ atmosphere. The coatings were deposited on commercially pure titanium (aTiO₂/cpTi) and stainless steel (aTiO₂/SS) substrates with a thickness of about 60-70 nm. For the SS substrates, a Ti buffer layer was used to improve the film-substrate adhesion. The results from different cell-surface interactions clearly show that a thin but dense and stoichiometric TiO₂ oxide film present a better biological response than the cpTi, even when deposited on the SS substrate. A significantly larger initial attachment (2 hours) of human osteoblasts cells was observed on the TiO₂ films in comparison to cpTi even at protein-depleted conditions, i. e, using serum-free culture media. The attachment was comparable to that obtained on collagen-coated plastic dishes (100%), while on cpTi only a 40% of attachment was obtained. The cell adhesion at longer period of times (24h and 7 days) was also demonstrated for human mesenchymal stem cells (MSCs). Similarly, a larger differentiation into osteoblasts of the MSCs was observed on the aTiO₂/cpTi coatings in comparison to the native oxide layers (cpTi) for two different surface roughnesses: smooth (0.3 µm) and micro-rough (2.6 µm). As a final test, the cell adhesion, differentiation and inflammatory response of MSCs on aTiO₂/SS surfaces was compared to the cpTi and the SS metallic surfaces. The results clearly show that the amorphous TiO₂ surfaces presented the highest expression of integrins and production of osteogenic proteins in comparison to the uncoated SS surfaces, reaching a very similar response to that presented by the typically used titanium surfaces. Moreover, the pro-inflammatory factors were inhibited while anti-inflammatory factors were up-regulated, demonstrating the advantage of using thin TiO₂ films for the development of orthopedic and dental implants with improve bone regeneration and osseointegration.

Acknowledgments: PAPIIT IN100116 and CONACYT 251279

2:50pm **D4-5 Antibacterial Thin Films with Controlled Antibiotics Release Based on Plasma Polymer**, *Vitezslav Stranak, J Kratochvil, D Kahoun, J Sterba, H Langansova, J Lieskovska*, University of South Bohemia, Czech Republic; *J Hanus, J Kousal, A Kuzminova, O Kylian*, Charles University in Prague, Czech Republic

Bacterial infections developed after implant surgery can cause serious medical complications for the patients. Current approach for infection suppression is to use systemic treatment of the patient by antibiotics. An alternative and very promising approach, that gains increasing attention, is to cover the surface of the implant with bioactive thin film, which prevents creation of the biofilm. Main benefit of this method are local treatment and possible supporting effect to the conventional systemic treatment.

Two different methods, which are able to gradually release antibacterial agents, will be presented. First method is based on immobilization of Ampicillin (i.e. common antibiotic) into magnetron sputtered Nylon 6,6 thin films. It was proven that Ampicillin is immobilized equally in the volume of Nylon 6,6 film, so it is possible to easily tune the amount of antibiotics in the coatings simply by changing their thickness. Controlled release kinetics can be achieved by deposition of diffusion barrier. Nanocomposite consisting of Cu nanoparticles, embedded into plasma polymerized PTFE represent the second method. Advantage of nanoparticles is their huge area against their volume, which reduces side effects of antibacterial metals in human body to minimum. Both methods are applicable to any substrate including smooth metals or polymers.

Acknowledgement: This work is supported by GACR 16-14024S.

3:10pm **D4-6 Development of a Microfluidic Based Multianalyte Biosensor Device for Medical Diagnostics**, *Emma MacHugh*, Dublin Institute of Technology, Centre for Research in Engineering Surface Technology (CREST), Ireland; *B Duffy, M Oubaha*, Centre for Research in Engineering Surface Technology (CREST), Ireland

Over the past decade, the biosensor research community has intensively investigated the development of innovative point-of-care (POC) devices often targeting the improvement of the platforms sensitivities for single analyte detection. However, in certain situations the detection of several in parallel is desired for economical and practical reasons, making the development of multianalyte platforms one of the most promising methodologies in the medical diagnostic industry.

Most biosensors also require an integrated microfluidic system for the flow of analyte liquids (blood, saliva and urine) onto the sensor areas of the POC. In order to enable a rapid and efficient delivery of these analytes, of the most important parameters, the surface properties of the microchannels have to exhibit as high a surface energy as possible. Unfortunately, to date, most materials employed in the fabrication of microfluidics are based on hydrophobic materials, the most popular of those being PDMS, and utilises low resolution fabrication processes, such as injection moulding and often require external pumps to activate the circulation of the liquids.

In this study, we propose a new fabrication concept of optical multianalyte biosensor platforms based on the integration of multiple sensor spots onto a microfluidic platform. The originality of the study resides in the development of high surface energy hybrid sol-gel materials that can be simultaneously photoreactive for microstructuring of high resolution microchannels by standard photolithography processes and irreversible immobilization of biological species. The preparation and characterisation of these innovative materials as well as the development of multianalyte biosensors will be presented. Correlation between the structure and surface properties of these materials along with the correlation of these properties against the fluidic performances of the biosensors platforms will be discussed. Finally, demonstration of concept of the multianalyte capability of the biosensor platform via optical fluorescence and a sandwich ELISA will be presented.

3:30pm **D4-7 Bactericidal Activity and Cytotoxicity of a Zinc Doped PEO Titanium Coating**, *Luciane Santos*, Pontificia Universidade Católica do Paraná, Brazil; *K Popat*, Colorado State University, USA; *P Soares*, Pontificia Universidade Católica do Paraná, Brazil

Metallic implants are susceptible to bacterial colonization even years after the implantation impairing the osseointegration process. The treatment of a colonized implant is highly demanding, and in most cases implant replacement is the only effective solution. To avoid the bacterial attachment and proliferation, bactericidal coatings are proposed as a long-term prevention tool. Those coatings must assure a bactericidal activity for a long period and cannot induce cytotoxic responses in eukaryotic cells. Among all the bactericidal agents Zinc is one of the most investigated due to its broad bactericidal activity spectrum and its stimulatory effect on bone formation. The aim of this study is to obtain a titanium oxide coating containing Zinc and evaluate its bactericidal activity, cytotoxicity and ion release profile. The coating was obtained by Plasma Electrolytic Oxidation (PEO) on commercially pure titanium grade 4 at 350 V for 60 s. Samples were divided in two groups, the reference group was obtained in a base electrolyte containing calcium acetate and calcium glycerophosphate (called CaP group). The experimental group has added Zinc acetate as a Zinc source to the base electrolyte (called Zn-CaP group). The surface was characterized by Scanning Electron Microscopy (SEM) and X-ray Photoelectron Spectroscopy (XPS), while the ion dissolution was evaluated by Inductively Coupled Plasma - Atomic Emission Spectroscopy (ICP-AES). The bactericidal activity was determined against *Staphylococcus aureus* by fluorescence microscopy using a live/dead viability kit. The cytotoxicity against eukaryotic cells was evaluated using adipose derived stem cells (ADSC) using the lactate dehydrogenase (LDH) assay. Zinc, Calcium and Phosphorus were incorporated to the titanium oxide coating and no changes on the coating structure and morphology were observed by the addition of Zn to the electrolyte. ICP-AES results show the coatings released Ca, P and Z ions after 28 days of immersion in DI water. The ICP-AES profile suggests the ion release reach an equilibrium state after 7 days of immersion. The Zn-CaP coating presented bactericidal activity against *S. aureus*, showing a higher number of dead bacteria after 6 h of incubation and a lower number of living bacteria after 24 h compared to CaP group. No cytotoxic effect was observed against ADSC by the presence of Zn on

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the coating, indicating the Zn-CaP coating has a potential to prevent bacterial colonization in metallic implants.

3:50pm D4-8 Antibacterial Effects of Titanium Embedded with Silver Nanoparticles Based on Electron-Transfer-Induced Reactive Oxygen Species, Guomin Wang, W Jin, A Qasim, A Gao, X Peng, W Li, H Feng, P Chu, City University of Hong Kong, Hong Kong

Although titanium embedded with silver nanoparticles (Ag-NPs@Ti) are suitable for biomedical implants because of the good cytocompatibility and antibacterial characteristics, the exact antibacterial mechanism is not well understood. In the present work, the antibacterial mechanisms of Ag-NPs@Ti prepared by plasma immersion ion implantation (PIII) are explored in details. The antibacterial effects of the Ag-NPs depend on the conductivity of the substrate revealing the importance of electron transfer in the antibacterial process. In addition, electron transfer between the Ag-NPs and titanium substrate produces bursts of reactive oxygen species (ROS) in both the bacteria cells and culture medium. ROS leads to bacteria death by inducing intracellular oxidation, membrane potential variation, and cellular contents release and the antibacterial ability of Ag-NPs@Ti is inhibited appreciably after adding ROS scavengers. The whole process can be found in Fig. 1. Even though ROS signals are detected from osteoblasts cultured on Ag-NPs@Ti, the cell compatibility is not impaired. This electron-transfer-based antibacterial process which produces ROS provides insights into the design of biomaterials with both antibacterial properties and cytocompatibility.

4:10pm D4-9 Tribocorrosion and Cytotoxicity of FeB-Fe₂B Layers on AISI 316 L Steel, I Campos-Silva, Instituto Politecnico Nacional, Surface Engineering Group, Mexico; M Palomar-Pardavé, Universidad Autonoma Metropolitana-A, Mexico; R Perez Pasten-Borja, Instituto Politecnico Nacional, ENCB Zacatenco, Mexico; O Kahvecioglu, Argonne National Laboratory, USA; D Bravo-Bárceñas, Universidad Autonoma Metropolitana-A, Mexico; C López-García, Rodolfo Yael Reyes-Helguera, Instituto Politecnico Nacional, Surface Engineering Group, Mexico

All metallic biomaterials are required to satisfy various criteria, such as adequate strength, high resistance to corrosion, biocompatibility, and high wear resistance. However, the various biomaterials that have been developed thus far do not satisfy all of the above requirements. Wear and corrosion have been reported to be the primary reasons for the failure of implant elements.

One alternative to reduce corrosion and wear is the boriding process. Boride layers have excellent resistance to crevice and pitting corrosion, high temperature performance as well as outstanding mechanical properties in corrosive environments. Based on that, new results about the tribocorrosion resistance and cytotoxicity of borided AISI 316 L steel are presented in this work. The powder-pack boriding process was conducted at 1273 K with 4 h of exposure, whereas a FeB-Fe₂B layer, with 50 microns of thickness, was obtained at the material surface. The tribocorrosion tests were performed in Hank's solution, using a ball-on-flat tribometer, which was connected with a three electro-chemical cell. The system comprised Al₂O₃ ball as the counterpart, the borided AISI 316 L steel as the working electrode, platinum rod as the counter electrode, and Ag/AgCl as the reference electrode. All sliding test, in the presence or absence of corrosion, was performed under 20 N normal force, considering a total sliding distance of 100 m.

The *in vitro* cytocompatibility of borided AISI 316 L steel was evaluated and compared with a conventional AISI 316 L steel. The immortalized human fibroblast CHON-002 and Vero established cell line from ATCC collection were used. Cells were exposed to conditioned leachates produced by immersion of the materials in culture medium (DMEM). Polyurethane film containing 0.1% zinc diethyldithiocarbamate (ZDEC) and polyurethane film containing 0.25% zinc dibutyldithiocarbamate (ZDBC), as well as high density polyethylene films were used as reference materials. Cells cultured in fresh medium was used as negative control. Cell viability was established with the cellular metabolic activity assay by means of MTT (3-(4,5-dimethylthiazol-2-yl)-2, 5diphenyl- tetrazolium bromide). The data were analyzed statistically by ANOVA, considering a significance of 5%.

The results showed that the presence of FeB-Fe₂B layer increases the tribocorrosion performance in comparison with the AISI 316 L steel. In addition, the AISI 316 L steel samples modified by boron denoted satisfactory properties in terms of effects on survival and proliferative activity of human fibroblasts; results that reveal that the boride layers are excellent candidates for the use as biomedical layers.

4:30pm D4-10 Optical Spectroscopic study for Atmospheric Pressure Plasma by Radio Frequency Power, Chuan Li, National Yang Ming University, Taiwan; J Hsieh, Ming Chi University of Technology, Taiwan; C Yu, National Yang Ming University, Taiwan

Atmospheric plasma techniques developed rapidly in the past decade. High-performance atmospheric plasma harnesses the power of plasma for surface treatment such as cleaning and coating. Due to the nature of atmospheric environment, the atmospheric plasma functions more like an ion carrier rather than reaction producer. This particular indicates that much less destructive processes such as ionization and excitation occur in the plasma zone. The less destruction implies more intact molecules or atoms survive their journeys through the plasma zone, which is crucial if one would like to maintain certain levels of the integrity of molecules delivered by the plasma to the surface of a substrate. Such a condition is particularly necessary for depositing macromolecules such as proteins, DNA/RNA in biomedical applications. It is also found useful in the task of surfaces activation and modification where the atmospheric plasma can be straightforwardly utilized for large scale productions without complicate vacuum facilities. The roll-to-roll process for coating and etching metallic or polymeric surfaces is a typical example in aviation, marine, automotive and civil applications. In this study, we investigate the effects of radio frequency of power and gas flow rates on the chemical compositions and morphology of atmospheric He plasma. A customized plasma system was setup and equipped with a radio frequency power supply, an optical emission/absorption spectrometer, deuterium halogen light source, x-y-z automated table, intensified charged coupled device camera, various flow controller and pressure gauges. The study focuses on the analysis of optical emission and absorption of spectra, temperature and power of He plasma by varying the radio frequency and flow rates. The chemical compositions of plasma are further analyzed using the optical spectra to identified possible ions and radicals. Along with the assistance of digital camera, additional information on the density of plasma is acquired for visualization. As a final touch, films of lactic acid are deposited on glass substrates via the He atmospheric plasma to demonstrate its capability as a carrier and reaction center.

Coatings for Biomedical and Healthcare Applications

Room Grand Hall - Session DP

Symposium D Poster Session

DP-2 Ti-Nb COATINGS Deposited on AISI 316L Stainless Steel by Magnetron Sputtering for Biomedical Applications, *E Gonzalez, D Tallarico*, Federal University of Sao Carlos, Brazil; *A Gobbi*, Brazilian Center for Research in Energy and Materials, Brazil; *C Afonso, Pedro Nascente*, Federal University of Sao Carlos, Brazil

AISI 316L stainless steel (SS) and Cr-Co alloys are commonly used for manufacturing biomedical implants due to their reasonably adequate bulk properties. Titanium and its alloys are more biocompatible, but also significantly more expensive, than SS and Co-Cr alloys. Ti-based alloys have an additional advantage compared to SS and Co-Cr alloys: their elastic modulus values are more compatible with those of the human bones (10-40 GPa). The elastic modulus values for AISI 316L, Cr-Co alloys, and pure titanium are 190 GPa, 210-253 GPa, and 105 GPa, respectively. The β -Ti (body cubic centered structure) alloys can have an elastic modulus even lower than 55 GPa. Niobium has been used as a nontoxic β -stabilizing agent, and its addition to Ti causes a decrease in the elastic modulus. An interesting option would be to coat an implant with a Ti-Nb thin film having adequate composition and thickness so that the coating would enhance the material biocompatibility. Care should be taken about the corrosion products of the biocompatible β -Ti-Nb coatings, since the implant devices are subjected to harsh environments into the human body and can deteriorate, affecting their service life and releasing potentially harmful particles generated by the corrosion processes which may affect the cell metabolism. Thus, the comprehension of the corrosion and osteointegration processes that occur on the metallic biomaterial surfaces is very important. In this work, β -Ti-Nb coatings were deposited on AISI 316L SS substrate by magnetron sputtering, and then were characterized by atomic force microscopy (AFM), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), transmission electron microscopy (TEM), and X-ray photoelectron spectroscopy (XPS). Four compositions were produced: 15, 20, 30, and 40 at.% Nb. The addition of Nb in the coatings affected their growth modes. The elastic modulus and the hardness values were in the ranges of 91.8-95.4 GPa and 5.4-7.4 GPa, respectively. The surface oxide layers were constituted of mainly titanium oxides and, to a lesser extent, niobium oxides. These partially oxidized surface layers are highly desirable for implant materials since they provide higher corrosion protection.

DP-4 Investigation of High Performance Hydroxylapatite Coated PEEK Composite Materials for Biomedical Applications, *J Su*, Chang Gung Memorial Hospital, Taiwan; *C Chen, Gwomei Wu*, Chang Gung University, Taiwan

Abstract In orthopedic surgery related to trauma or disease, it often requires the use of artificial bone plate to hold the fractured bones to effectively heal the fracture of a long bone. During surgery and postoperative healing period, the antibiotic management is critical to patients with infection control. A wound healing is also promoted by osteointegration and bone regeneration. A proper system needs to be effective to treat the wound, to reduce pain, and to restore function of a healthy life. High performance polyetheretherketone (PEEK) biomedical composites have been investigated for bone plate applications. By appropriate design, the biomedical composite materials can match the different parts of human body bones, quite helpful for long-term functional rehabilitation after surgery. They also remain x-ray transparency, making it easier for clinicians to assess the healing process. We have been developing PEEK composites with biodegradable polylactic-co-glycolic acid (PLGA) double layer structure bone plates and hydroxylapatite (HA) to promote bone regeneration and to derive antibiotic applications. In this report, the analysis of the material characteristics, in-vitro tests, and comparison with literature data will be presented and further discussed. A good understanding in the structure-property relationship would provide better guidelines for implant designs.

DP-5 Structural and Morphological Properties of PEO Films Grown on Ti-10Nb and Ti-20Nb and their Cellular Viability, *Carlos Lepiński*, Universidade Tecnológica Federal do Paraná, Brazil; *A Luz*, UFPR, Brazil; *N Kuramoto*, Universidade Federal do Paraná, Brazil; *G Lima*, Athlone Institute of Technology, Ireland; *B Pereira*, Universidade Federal do Paraná, Brazil; *M Sá, D Lima*, Universidade Federal de Campina Grande, Brazil

Recent investigations have been focused on β type titanium alloys as they present biocompatibility, non-toxicity, improved mechanical properties and also exhibit corrosion resistance. These novel alloys are bioinert, consequently surface modifications are required to improve its bioactivity. Plasma Electrolytic Oxidation (PEO) can be employed to produce a porous film which contains oxides of elements that compound the titanium alloys, that is known to exhibit good bioactivity and biocompatibility. With the continuous interest in titanium alloys, the purpose of this study was to modify two different titanium-niobium surfaces via PEO and understand the structure of these films while also analyzing the improvement in bioactivity via cellular viability. Ti-10Nb and Ti-20Nb alloys were treated by PEO under 250 V in $1\text{mol.l}^{-1}\text{H}_3\text{PO}_4$ electrolyte during 60 s. For the samples characterization we perform metallographic analysis, X-ray diffraction, Scanning Electron Microscopy (SEM), Energy Dispersive X-ray Spectroscopy (EDS), Nanoindentation technique, and cellular viability tests with MC3T3 cells with further analysis on SEM to understand the cellular behavior with the titanium implants. Metallographic analysis and X-ray patterns showed that Ti-10Nb and Ti-20Nb are composed by (α + β) which were due to the process performed above the β transus temperature to a (α + β) region, and the slow rate of cooling during the manufacturing process. Nanoindentation testes revealed that Ti-20Nb alloys exhibited the highest value to hardness, (3.0 ± 0.2) GPa, and the lowest elastic modulus, 98 ± 2 GPa. Using the 3D view of SEM technique, Ti-Nb coatings presented important values of roughness with round porous and random diameters. In addition, these images presented values of thickness from $\sim 1.7 \mu\text{m}$ for Ti-10Nb and $1.0 \mu\text{m}$ for Ti-20Nb. Due to the electrolyte used, the presence of phosphorous compound which was incorporated into the coating during the PEO process was detected by the EDS spectra. X-ray patterns exhibited a highly crystalline film on Ti-10 Nb alloy which was also observed in great intensity with Raman spectroscopy with anatase phase. Conversely, Ti-20Nb presented a highly amorphous film with a decrease amount of bands of anatase phase observed by Raman spectroscopy. Cellular viability with MC3T3 cells showed no signs of cytotoxicity of these alloys with values higher than the control sample ($>70\%$) but no significant differences were observed between these alloys; although TiNb10% presented mean higher values. These cells attached, differentiated and proliferated well in these alloys due to the porosity, roughness and the elements presented in the film.

DP-6 Tribocorrosion Behavior of SiC Films with and without TiO₂ Nanoparticles on AISI 316L for Prosthesis Application, *A Vieira, T Santos*, Univap, Brazil; *P Radi*, ITA, Brazil; *S Silva*, IEAv, Brazil; *A da Silva*, Univap, Brazil; *G de Vasconcelos*, IEAv, Brazil; **Marco A. Ramirez R.**, Universidade do Vale do Paraíba (UNIVAP), Brazil; *L Vieira*, Univap, Brazil

Stainless steel (AISI) materials have an important role in the manufacture of many devices subjected to the corrosive environment including implants. It occurs due to their higher mechanical strength, hardness, and resistance to wear. Regards to the AISI 316L, it is one of the most used implanted material due to its mechanical properties and low cost. However, many papers have been reporting its tribocorrosion and the need of replacement before ten years. The deposition of Silicon Carbide (SiC) coatings is a cheap strategy to improve its lifetime in corrosive environments due to its properties such as high hardness, biocompatibility, and resistance to corrosion. Additionally, TiO₂ nanoparticles can be incorporated into the SiC films to improve its corrosion resistance.

This paper show was investigated the effect TiO₂ nanoparticles of SiC film on chemical structure, the film morphology, and tribocorrosion behavior in Ringer's solution. The AISI 316L substrates were covered with SiC films with and without TiO₂ nanoparticles using Laser Cladding technique. The laser cladding provides a fast and cheap way to modify the material surface. The mechanical and structural properties of the SiC films were evaluated according to the power and speed parameters of the laser. The tribocorrosion were performed using open circuit potential (OCP) performed in three steps: Static, reciprocating, and static modes with an exposed area of 1.5 cm^2 with 5N force and 5 mm/s sliding speed using an alumina ball as the counter body. The corrosion rate was lower for both films when compared with bare AISI 316L. The best tribocorrosion resistance result was achieved for SiC film+TiO₂ mixture.

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