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 d 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 SML-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.

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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℃ 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.

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