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EDITORIAL

Surface and Interface Studies for Improved Performance of Metallic Parts and Devices

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This work is to reveal and present some contemporary surface treatment methods used in view of improving performance of parts of a variety of metals and alloys. Stainless steels and titanium alloys are with the group of particular focus, important for medical implants in chirurgy and instruments used in dentistry. Improved, anti-corrosion properties and mechanical strength of materials are the primary features for examination.

Typical processing methods used for surface finishing cover:

- Mechanical//abrasive polishing
- Electrochemical machining//shaping process (used under pressure)
- Electrochemical Polishing (EP), known as the electropolishing, or electrolytic//anodic polishing
- High-Current Density Electropolishing (HDEP)
- High-Voltage Electropolishing (HVEP)
- MagnetoElectropolishing (MEP), the electrolytic polishing used under magnetic field [1,2].

All these electrochemical finishing processes are used to elevate surface roughness, improve the surface quality of metallic parts as well as to passivate the surfaces for increasing corrosion resistance: basically they are to exhibit their advantage in comparison with other traditional surface treatments//abrasive polishing. Each of these electrochemical processes provides a specific property to the metal/alloy surface by creating a new microstructure and thickness of the controllable oxide film layer. Thanks to the non-contact action of electrolyte used in these electrochemical processes, any residual stress is vanishing: this way the obtained surface features are vital to a variety of advanced applications, starting from general use of metallic parts in different environments to particular metallic biomaterials and instruments applied in medicine and dentistry.

Beginning from the surface roughness decay and gloss effects appearance, which are usually natural effects of the EP processes, another important feature of electropolished surfaces is an enhanced corrosion resistance of the treated metals and alloys. They were studied and proved their advantage on the following materials: stainless steels (AISI 304, 304L, 316, 316L, 316L VM), valve metals (such as Al, Ti, Ta, Nb which pass current in only one direction; as well as Cr, Zr, Hf, Zn, V, Bi, Sb, Pb), and other alloys, e.g. cobalt alloy M605, titanium alloys – such as Nitinol NiTi

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SMA, Ti6Al4V, ternary TNZ – titanium-niobium-zirconium alloy, and Ti2448 – Ti-24Nb-4Zr-8Sn – material of super plasticity. The electrochemically treated metallic materials reveal also other numerous superior features, such as unique surface films obtained with characteristic topography of specific wettability, and considerably improved biocompatibility. For instance, stainless steels after MEP are more resistant to halides encountered in a variety of body fluids, such as blood, saliva, urine, etc. The common environments adopted for the studies cover pure distilled water (as a reference fluid), the Ringer's body fluid, and 3% NaCl aqueous solution as the most aggressive environment.

During MEP of alloys, magnetic elements such as iron in austenitic stainless steels, or nickel in Nitinol can be completely removed from the surface layer. This way, the surface film on stainless steel becomes highly enriched in chromium oxides; also mostly Titanium Oxide (TiO_2) is formed on NiTi alloy surface. Following our finding, referred to the MEP treatment, is a substantial increase of mechanical properties, specifically referred to the improved fatigue effect under samples bending.

Another quest is de-hydrogenation appearing/materializing during electrolytic processes. Hydrogen depth profiles after conventional EP and MEP under natural and forced convections were compared to reveal that the increased current density, up to 200 A/dm2, and electrolyte stirring resulted in lowering the hydrogen content in the stainless steel samples, with the greatest decrease obtained after Magneto Electropolishing (MEP200). Nano-layers with different chemical compositions are obtained during HDEP, HVEP, and MEP, in comparison to the composition after a standard EP.

The investigation methods used for the metallic samples – apart from the conventional 2D and 3D roughness studies – generally cover Scanning Electron Microscopy SEM/EDAX (Electron Dispersive X-ray Spectroscopy), Atomic Force Microscopy AFM, Auger Electron Spectroscopy AES, X-ray Photoelectron Spectroscopy XPS (also known and Electron Spectroscopy for Chemical Analysis ESCA), X-Ray Diffraction analysis XRD, Secondary Ion Mass Spectroscopy SIMS, and Glow Discharge Optical Emission Spectroscopy GDOES examinations. They are normally to get qualitative, quantitative, chemical state, and depth information. Afterwards, a particular approach is directed to study biological behavior to assess the biocompatibility of the samples after electrochemical treatments.

The electrochemical studies routinely start with the open-circuit potential and polarization curve characteristics measurements. Both Alternating (AC) and Direct (DC) currents have been applied for the experiments. For electrochemical characterization of metallic biomaterials, potentio dynamic polarization and electrochemical Impedance Spectroscopy (EIS) tests are usually performed in artificial saliva solution at 37 °C, by utilizing a potentiostat/galvanostat instrument with a three-electrode configuration. Wettability is assessed by measuring the contact angle of a droplet of de-ionized water with the use of a digital microscope.

Plasma Electrolytic Oxidation (PEO), known also as Micro-Arc Oxidation (MAO), has been developed for years now and it used to be essential to modify the surface features of metals and alloys (mostly stainless steels and titanium-based alloys) [3,4]. It serves to obtain a developed surface layer enriched with the elements coming from the electrolyte used. The PEO processes allow creating and forming the micro-layers, with a variety of expected compositions and the properties on request. The PEO processing has been an important surface treatment method that can improve the corrosion resistance and cellular response in the biological environment. That way created the adhesive developed surface layers on the metallic parts and/or devices manufactured of valve metals and their alloys are of high importance in contemporary medicine. The main advantage of the PEO process is altering the biological properties of the created layer, with controlled chemical composition, in view of attaining better functioning in the biological medium.

After electropolishing and/or PEO processes a distinctive biological examination of the samples is performed. Antibacterial activity is evaluated by exposing the sterilized metal/alloy samples using *E. coli* bacterial suspension at a generally accepted concentration, time (mainly 24 h) and temperature. Based on these results, the antibacterial performance is determined from the percentage of the number of the missed bacterial colonies to the number of the control colonies after 24 h incubation period. It appears, combining calcium, phosphorus, and copper elements on the surface of a metal/alloy substrate greatly improves the antibacterial properties and osteoblastic cellular response. Following this way, a significant diminishing of the risk of bacterial infection after chirurgical operation and/or cytotoxicity of dental implants is attained.

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