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Mini Review

Exploring the Role of Antibacterial Nanoparticles Addition in Biodeterioration of PEO-treated Ti-base Alloys: A Mini-Review

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Ti-base alloys possess a wide variety of attractive properties, including, but not limited to, good biocompatibility, excellent corrosion resistance, satisfactory mechanical characteristics and high specific strength, making them viable candidates for biomedical applications [1]. Nonetheless, the inappropriate bone bonding of these alloys and the subsequent accumulation of abrasive particles at the alloy/tissue interface lead to implant failure. Meanwhile, the biodeterioration of many Ti-alloys, like Ti6Al4V, would be accompanied by the release of hazardous metal ions akin to aluminum and vanadium into the surrounding tissue and body fluid, which in turn results in health problems, including allergy, toxicity and inflammation. Consequently, the necessity to apply protective coatings upon the surface of such an alloy is highly demanding [2].

According to the literature published to date [3], various types of surface modification techniques (e.g. sol-gel method, chemical vapor deposition and electrophoretic deposition) have been employed so as to improve the surface features of the titanium alloy. In this regard, the plasma electrolytic oxidation (PEO) method (i.e. often termed micro-arc (discharge) oxidation, micro plasma oxidation or spark anodizing) has emerged as an effective, inexpensive and environmentally friendly means of producing porous ceramic coating upon the surface of valve metals, akin to Ti-base alloys [4]. In terms of the PEO procedures, the application of overpotentials exceeding the dielectric breakdown voltage would unsterilized the resulting oxide film in such a way that gas evolution, light incidence, micro-discharging and sparks occur due to chemical reactions taking place on the surface of the anode. Accordingly, the pressure and temperature of the aqueous electrolyte inside the discharge channels increase dramatically to the range of 100-1000MPa and 2000-10000K, respectively, which is followed by the creation of a well-adhered, corrosion- and wear-resistant coating having a dual-layer structure (i.e. the inner barrier layer and outer biocompatible film) [5,6]. The quality and performance of the PEO coatings can be directly linked to processing parameters (i.e. the treatment time, applied potential, the magnitude of the current passing through the cell and the corresponding frequency), electrolyte properties (i.e. temperature and chemical composition of the solution) and the presence of additives. Primarily, the addition of additives (e.g. oxide particles) to the PEO bath can have a discernible impact on the conductivity of the solution, breakdown voltage and final voltage, which in turn alters the morphology, chemical composition, electrochemical response and wear resistance of the PEO-coated alloy [7]. According to the latest studies conducted into this matter, the addition of nanoparticles (NPs) or micro-particle of Al-, Ce-, Si-, Ti-, and Zr-based oxides (as additives) to the coating electrolyte can boost the corrosion resistance and tribological properties of valve metals [8]. Depending on the chemical composition of the PEO electrolyte, applied overvoltage and properties of the particles (e.g. melting point, chemical stability and size), the additive embedment within the coating can occur via reactive and/or non-reactive conditions [9].

The concentration, size and melting point of the nanoparticles, as well as their zeta-potential, can substantially influence the adsorption of protein, antibacterial activity and cell proliferation of the resulting PEO coatings [10]. Taking into account it that several NPs exhibit antibacterial activities, there has been a growing trend among researchers to investigate and enhance the biocorrosion resistance and bactericidal effects of the antibacterial NP-reinforced nanocomposites formed on the surface of Ti-alloys. In the case of ZnO NPs [8], it has been reported that the incorporation of particles into the coating formed upon the pure Ti can impede corrosion and increase the intensity of the antibacterial effect. The biocompatibility of Ti alloys subjected to PEO treatment in baths containing antibacterial Ag NPs has also been the objective of previous studies [11,12], indicating improved biocorrosion resistance along with outstanding antibacterial ability. To the best of our knowledge, the corrosion behavior and biocompatibility of the PEO composite coatings reinforced with other antibacterial agents have remained unexplored to date. Specifically, Ag_2O, CuO and Y_2O_3 NPs have not been added to PEO bath of Ti-alloys. Hence, one can deduce that the investigation of morphology, chemical composition, electrochemical corrosion properties and antibacterial activities induced by the incorporation mechanisms of the antibacterial NPs in the resultant PEO films can provide a revealing insight into the tunning biocompatibility and corrosion performance of Ti-base alloys for future generations of implants.

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