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Antibacterial properties of vacuum plasma sprayed titanium coatings after chemical treatment

Yikai Chen, Xuebin Zheng *, Youtao Xie, Heng Ji, Chuanxian Ding

Key Laboratory of Inorganic Coating Materials, Chinese Academy of Sciences, Shanghai, China
Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai, China

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ABSTRACT

Implant-related infection is one of the common clinical complications that cause high rates of mortality and morbidity in orthopedic surgery. Endowing implant antibacterial properties is a useful method to reduce such infection. In this paper, vacuum plasma sprayed titanium coatings were treated by NaOH solution firstly, and then antimicrobial silver was introduced into the coatings by immersing in 0.02 mM (denoted as CA1), 0.06 mM (denoted as CA2) and 0.1 mM (denoted as CA3) Ag^{+} containing calcification solution. Antibacterial property of the treated titanium coatings was examined by employing three types of bacteria stains, *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. X-Ray diffraction and scanning electron microscopy were used to observe the phase composition and surface morphology of the modified titanium coatings. Results showed that all of the three kinds of coatings exhibited more than 90.00% antibacterial ratio except CA1 to *Staphylococcus aureus* which is 63.30%. The release of silver in physiological environment was monitored and it was found that the excellent antibacterial property of the treated coatings was attributed to the release of silver.

1. Introduction

Titanium and titanium alloys are the metals of choice in orthopedic and dental applications because of their biocompatibility, light weight and high mechanical strength [1–3]. In order to further improve the fixation of implant clinically, a macroporous titanium coating is usually formed by sintering titanium beads or plasma spraying titanium power on the implant. However, the titanium coatings usually suffer certain disadvantages, such as poor osteoinductive and implant-related infection [4,5].

Implant-related infection is considered to be common clinical complication that causes high rates of mortality and morbidity in orthopedic surgery, and the problem usually causes removal of the prosthesis and second operation, thus increasing health care costs [5]. In order to reduce the risk of infection, prophylaxis is usually carried out by intravenous injection of an antibiotic before surgery, but high concentrations of drugs in blood for a long period may induce toxicity [6]. Local antimicrobial delivery by implant may increase the antibiotic dosage near the affected site thereby improving efficacy and reducing the treatment duration [7], and decrease the side-effects of systemic treatments [8]. As biomaterials, not only the biocompatibility and physical and chemical properties are important, but also the antibacterial property plays an important role as well. It is recognized that implants with antibacterial performance would be crucial to prevent these bacterial infections [9].

It is well known that silver shows good antibacterial properties without any toxic effects in comparison with other heavy metal ions. Klasen [10] reported silver has long played a role in the treatment of burns. Gosheger et al. [11] found that the infection rate of silver-coated medical devices has been reduced in animal experiment. Our previous study showed that the vacuum plasma sprayed titanium coatings after immersed in NaOH solution and supersaturated calcification solution possessed good bioactivity [12]. It could be an effective way to introduce antibacterial silver into titanium coating by the treatment of silver-containing calcification solution meanwhile maintaining bioactivity for the coating.

In this paper, silver-containing titanium coatings were fabricated by chemical treatment. The obtained coatings were characterized by means of X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM). The antibacterial property of the coatings was investigated employing three types of bacteria stains, *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. The release of silver in physiological environment was monitored by leaching test.

2. Materials and methods

2.1. Specimen preparation

Commercially available titanium powder (GfE, Germany) with typical sizes of 40–120 μm was used to prepare titanium coatings on

* Corresponding author. Tel.: +86 21 52411025; fax: +86 21 52413903.
E-mail addresses: chenyikai7@hotmail.com (Y. Chen), xbzheng@mail.sic.ac.cn (X. Zheng).

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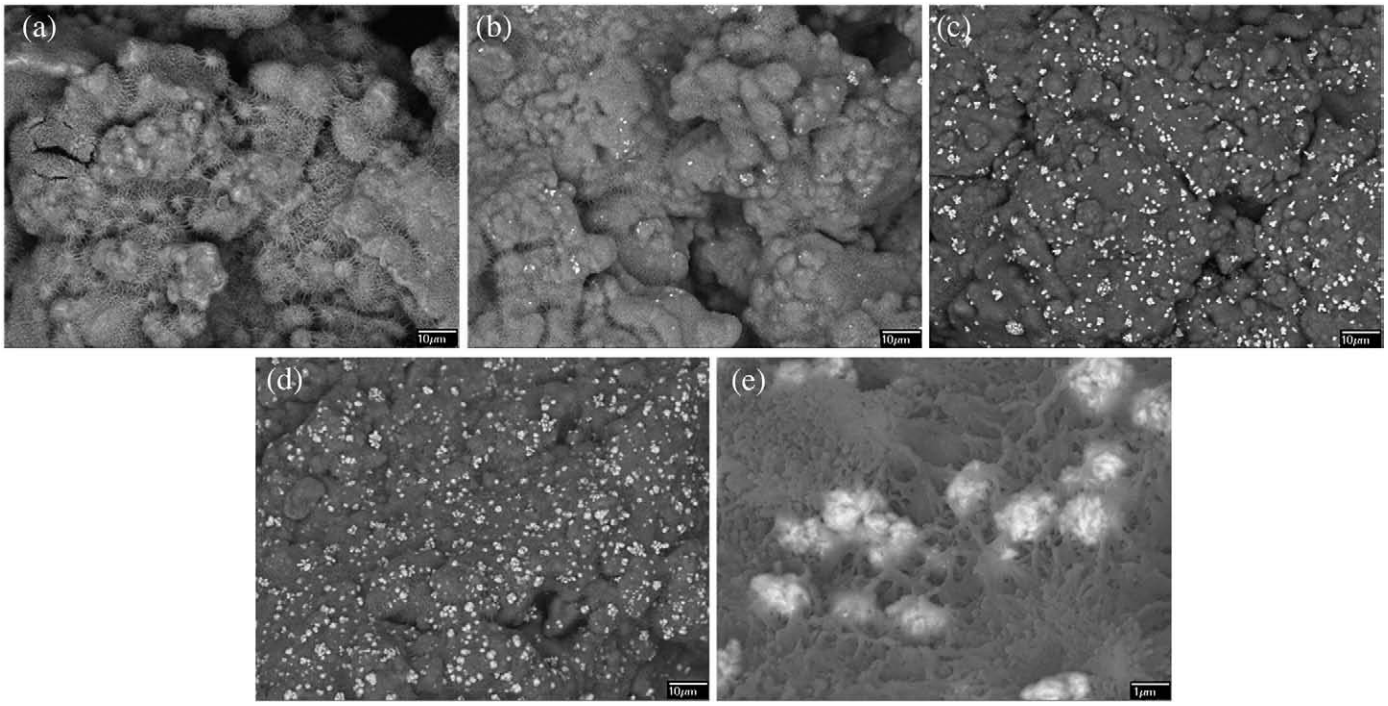

Fig. 1. Surface morphologies of the treated titanium coatings: (a) CA, (b) CA1, (c) CA2, (d) CA3, (e) high magnification of CA3.

the surface of Ti–6Al–4V alloy plates of $10\times30\times2$ mm^3. Vacuum plasma spraying (VPS) system (Sulzer Metco, Switzerland) was applied to fabricate titanium coatings with modified spray parameters [2].

The silver-containing calcification solution was prepared by dissolving $Ca(NO_3)_2\cdot4H_2O$ (3.75 mM), $K_2HPO_4\cdot3H_2O$ (1.50 mM), $NaNO_3$ (142 mM) and diverse amount of $AgNO_3$ in de-ionized water, and buffered to pH 7.4 by TRIS (tris(hydroxymethyl) aminomethane) and HNO_3 at a temperature of 25 °C. The concentration of $AgNO_3$ in the solution was respectively 0.02 mM, 0.06 mM and 0.1 mM.

After being ultrasonically cleaned in distilled water, the coatings were soaked in 5.0 M NaOH solution at 60 °C for 24 h, then washed with distilled water and dried at 40 °C for 24 h in air. Subsequently the coatings were soaked in the silver-containing calcification solution at 25 °C for 48 h. And then the coatings were dried at 120 °C for 2 h in air atmosphere. The coatings were denoted as CA1, CA2 and CA3. The titanium coatings, treated similarly but using silver-free calcification solution, were used as control (CA).

2.2. Specimens analyses

The surface and cross-section morphologies of the treated coatings were observed by scanning electron microscopy (SEM, JSM-6700F,

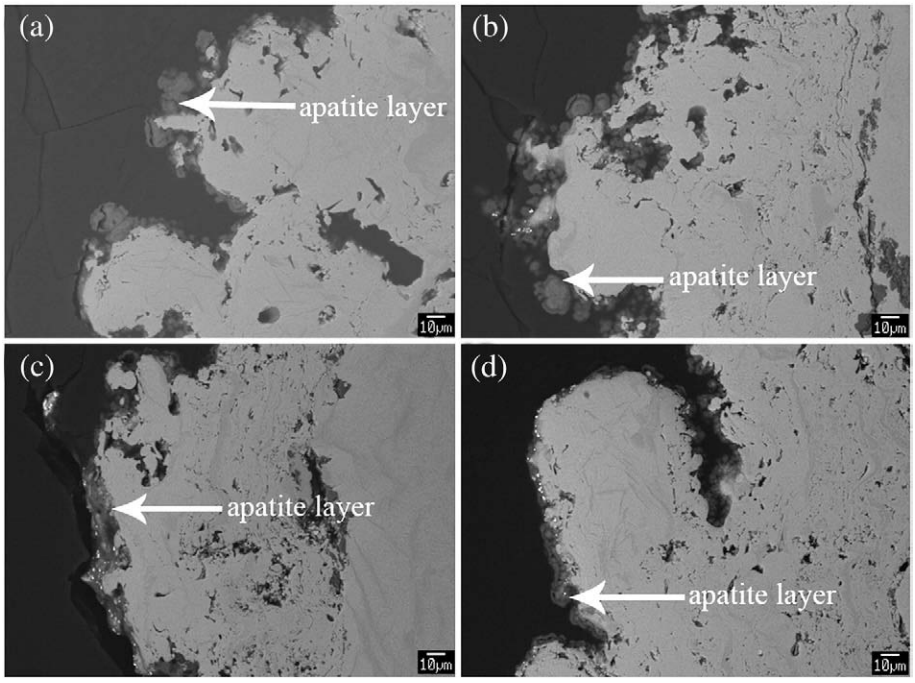

Fig. 2. Cross-section morphologies of the treated titanium coatings: (a) CA, (b) CA1, (c) CA2, (d) CA3.