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Tribological Behavior of Bone Against Calcium Titanate Coating in Simulated Body Fluid

Comportamiento tribológico de hueso contra recubrimiento de titanato de calcio en fluido corporal simulado

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Abstract

Although calcium titanate has been proposed as a coating for biomedical applications, a characterization of tribological properties simulating human conditions has not been reported. In this work we studied friction and wear mechanism of calcium titanate coating growth onto AISI 304 steel (750 nm thickness) deposited by r.f. magnetron sputtering. It was found that the wear mechanisms of the system is bone adhesion to the coating without detachment of the coating, both dry and in Hank's solution, with a friction coefficient of 0.84 ± 0.13 and 0.65 ± 0.13, respectively. The wear of the bone was more severe when using a simulated body fluid at 37°C in the pin on disk test.

Keywords:

- biomaterials
- calcium titanate coating
- tribology
- pin-on-disk
- Hank's solution

Resumen

Aunque el titanato de calcio ha sido propuesto como recubrimiento para aplicaciones biomédicas, no se han reportado caracterizaciones tribológicas en condiciones que simulan las condiciones del interior del cuerpo humano. En este trabajo se evalúan propiedades de fricción y mecanismos de desgaste de estos recubrimientos (de 750 nm de espesor) depositados mediante r.f. magnetrón sputtering. Se encontró que el mecanismo de desgaste del sistema es adhesión de hueso al recubrimiento sin desprendimiento de la capa, tanto en seco como en solución de Hank, con coeficientes de fricción de 0.84 ± 0.13 y 0.65 ± 0.13, respectivamente. El desgaste del hueso fue más severo cuando el ensayo de pin-disco se llevó a cabo en fluido corporal simulado.

Descriptores:

- *biomateriales*
- *recubrimiento de titanato de calcio*
- *tribología*
- *pin-disco*
- *solución de Hank*

Introduction

Hip prosthesis stems may be cemented or uncemented, the uncemented have four options for achieving adhesion with the surrounding tissue: by pressure, porous surface, screws or with coated surface. Joint prosthesis with hydroxyapatite coated stems have presented a big clinical success, as they increase the rate of osseointegration regarding uncemented prosthesis (Faig and Gil, 2008; Coathup *et al*., 200; Rokkum and Reigstad, 1999). However, in the long run this coating dissolves and detaches exposing the base metal (Porter *et al*., 2004), which can lead to the loosening of the prosthesis, pain in the patient, wear on the rest of the prosthesis or, in the worst case, to extensive destruction of bone tissue.

Although the calcium titanate has been studied extensively in regard to optical and luminescent properties (Moreira *et al*, 2009; Wang *et al*., 2009; Yang *et al*., 2009), an interface layer containing calcium titanate on biomedical titanium alloys coated with hydroxyapatite has been found (Ergun *et al*., 2003; Kokubo *et al*., 2003), so that some authors have reported to have obtained calcium titanate layers by various methods on titanium and titanium alloys, such as sol-gel (Holliday and Stanishevsky, 2004), magnetron sputtering (Asami *et al*., 2005), ion-beam assisted deposition (Ohtsu *et al*., 2006), pulsed laser deposition (Ohtsu *et al*., 2007), hydrothermal–electrochemical method (Wiff *et al*., 2007), thick alkalized calcium oxidation (Ohtsu *et al*., 2007), and hydrothermal treatment (Park *et al*., 2011) for biomedical applications.

Despite the fact that most commercial prostheses are made of titanium or titanium alloys, because the material replaced for bone is expected to have a modulus equivalent to that of bone (Geetha *et al*., 2009), and due to their high cost and their poor tribological properties, stainless steels is still used in hip prosthesis and remains under investigation for biomedical purposes (Lundin *et al*., 2012; Nie, 2011; Barragán *et al*., 2010). Although type 304 is seldom used in biomedical implants or devices and its sensitivity to any sign of corrosion is more detectable than in 316L (Tang *et al*., 2006), it is used in implants such as brackets and screws. This steel also meets ASTM F138 y ASTM F139 (ASTM F138–08, 2008; ASTM F139–08, 2008) standards for steels used in biomedical applications and it is cheaper than AISI 316L which would represent a reduction in hip prosthesis cost. This is the reason for proposing here the evluation of tribological properties of AISI 304 stainless steel coated with calcium titanate for prosthesis stem applications.

It is known that due to the continuous micro-movements between the bone and the implant (Fu *et al*., 1998) wear femoral stem occurs (Howell *et al*., 1999), so it is important to know the tribological properties of the coating with respect to the bone, such as friction and wear in conditions which approach those of the human body. Therefore, this work aims to evaluate calcium titanate coated AISI 304 stainless steel by r.f. magnetron sputtering, evaluating mechanical properties of hardness and elastic modulus by nanoindentation; coefficient of friction and wear by pin-on-disc test in dry conditions at room temperature and in Hank's solution at 37 °C with an animal bone pin as a counterpart.

Materials and methods

The $CaTiO_3$ cathode used for the sputtering technique were from $CaTiO_3$ powder with a purification of 99.9% from Super Conductor Materials, Inc. Silicon (100) and 304 stainless steel disks (diameter = 1.27 cm and thickness = 3 mm) were used as substrates. The steel was polished with sandpaper passing numbers 200 to 2000, and finally with 1 and 0.3 μm alumina solution. Prior to deposition of calcium titanate an approximately 200 nm