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Influence of Bio-Lubricants on the Tribological Properties of Ti6Al4V Alloy

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Abstract

Titanium alloy is one of the best materials for biomedical applications due to its superior biocompatibility, outstanding corrosion resistance, and low elastic modulus. However, the friction and wear behaviors of titanium alloys were sensitive to the environment including lubrication. In order to clarify the wear mechanism of titanium alloy under different lubrications including deionized water, physiological saline and bovine serum, the friction and wear tests were performed between Ti6Al4V plates and Si_3N_4 ball on a universal multi-functional tester. The friction and the wear rate of titanium alloy were measured under dry friction and three different lubrication conditions. The worn surfaces were examined by scanning electron microscopy. The results revealed that under the dry friction, the wear resistance of titanium alloy was the worst since the wear mechanism was mainly the combination of abrasive wear and oxidation wear. It was also found that Ti6Al4V alloy had low friction coefficient and wear rate under three lubrication conditions, and its wear mechanism was adhesive wear.

Keywords: titanium alloy, lubrication, friction coeffitient, wear mechanism

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1 Introduction

Titanium and its alloys are known as the most appropriate materials for biomedical applications due to their superior biocompatibility, outstanding corrosion resistance, and low elastic modulus comparable with that of human bone[1–6]. However, the poor tribological performance of titanium alloy limits its use in wear-related engineering applications, especially in artificial joints[7].

There were a lot of reports on the friction and wear of titanium alloys during the past two decades and many efforts were made attempting to provide a better understanding of wear mechanisms of titanium alloys. According to the research of Molinari *et al*.[8], the poor tribological properties of titanium and its alloys were attributed to the low resistance to plastic shearing, the low work-hardening and the low protection exerted by the surface oxide. As we known, the surface oxide was easily removed by spalling and could not protect the subsurface layers against wear. Güleryüz and Cimenoğlu highlighted that the formation of wear debris fallen of the surface oxide and release of metal ions caused adverse tissue reactions, implant loosening and eventual revision surgery[9]. Therefore, there were many early works focusing on different surface modification ways to improve the tribological performance of titanium alloys, including Physical Vapor Deposition (PVD), plasma immersion ion implantation, thermal oxidation, plasma and laser nitriding and so on. Liu *et al*. reviewed some methods about surface modification to enhance the wear resistance of titanium and its alloys for biomedical applications[10]. Recent works indicated that different components of the lubricants such as phospholipid, proteoglycan molecules, hyaluronic acid, and gelatin had significant effects on the friction and wear of ultra-high molecular weight polyethylene[11–14]. Scholes and Unsworth investigated the effects of proteins on the friction and lubrications of artificial joints, including the CoCrMo alloy and UHMWPE[15]. However, there are few reports on the effects of different lubricants on the tribological behaviors of titanium alloys. Therefore, it is essential to fully understand the wear mechanisms of titanium alloy under biolubrication systems. Ti6Al4V alloy was chosen in this experiment because it is one of the most widely used titanium alloys.

The wear behavior of a sliding system depends on many factors, including the properties of the specimen

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and counter-face materials, their interaction with the environment and the experimental conditions[16,17]. In this work, the friction and wear tests were performed between Ti6Al4V plates and Si_3N_4 ball on a universal multi-functional tester to research the effects of different lubrication systems including deionized water, physiological saline and bovine serum on the wear mechanisms of titanium alloys.

2 Experimental

In the present study, the Ti6Al4V specimens were machined in a 20 mm × 20 mm square shape with 5 mm thickness. Before performing experiment, the samples of Ti6Al4V were polished to reach the roughness of 0.04 μm, and then they were ultrasonically cleaned by ethanol for 30 min. Si_3N_4 ball with 4 mm diameter and 0.02 μm roughness was chosen for wear test due to its super wear resistance and excellent chemical stability. During the experiment, the friction and wear behaviors of titanium alloy were investigated under four conditions including the dry friction, deionized water, physiological saline and bovine serum, respectively.

The sliding wear test of Ti6Al4V was performed on a Universal Multifunctional Tester (UMT) with the ball-on-flat style under dry friction and three different lubrication conditions. The schematic of contact between Si_3N_4 ball and Ti6Al4V plate was shown in Fig.1. During the process, the titanium alloy specimen was fixed to the specimen holder and the Si_3N_4 ball was implemented reciprocating motion continuously.

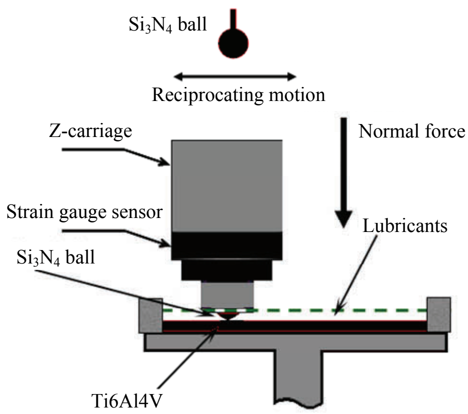

Fig. 1 The schematic of ball-on-flat style wear test.

The normal force during the friction and wear test was set to 9.8 N, which corresponded to the contact pressure of 1.45 GPa. The sliding speed and reciprocating displacement of Si_3N_4 ball were 4 mm·s^{-1} and 6 mm respectively for the wear test. The coefficient of friction was digitally recorded throughout 30 min test by a load transducer. After wear test, the loss of weight was measured by electronic balance with an accuracy of 0.00001 g. Then the wear rate was calculated by Eq. (1). The worn surface of Ti6Al4V alloy was examined by Scanning Electron Microscope(SEM), and the Ti6Al4V specimens under lubrication conditions were cleaned to remove the liquid from the surfaces before placing them into the SEM.

$$\omega = \Delta m / (F \cdot S), \tag{1}$$

where ω is wear rate, Δm is the weight loss, F equals to 9.8 N, and S is the total sliding distance, $S = 4$ mm·s^{-1} × 30 min× 60 s·min^{-1} = 7200 mm = 7.2 m.

3 Results and discussion

3.1 Coefficient of friction and wear rate

Fig. 2 shows the curves of the friction coefficient of Ti6Al4V against the Si_3N_4 ball under dry friction and three different lubrication conditions. The common features of friction curves were heavy fluctuations under dry friction while lubrication conditions result in a significant reduction in both the value and the fluctuation of friction coefficient curves. Table 1 shows the average Coefficient of Friction (CoF) and the variance of Ti6Al4V under four conditions, including the dry friction, deionized water lubrication, physiological saline lubrication and bovine serum lubrication, respectively. The average value and the variance of CoF were calculated when the three CoF curves under lubrication remained constant after certain testing periods (600 s). It was also found that the value of CoF and the variance of Ti6Al4V alloy under three lubrication conditions decreased compared to dry friction. The average values of CoF in the deionized water, physiological saline, and bovine serum dropped by 10.47%, 19.50% and 31.32% compared with the CoF around 0.68 under dry friction condition, and the variance of CoF had a greater reduction.

The results of wear rate of Ti6Al4V under four conditions are shown in Table 2. It was found that Ti6Al4V alloy had the most severe wear under dry friction. The wear rate of Ti6Al4V under the lubrication of physiological saline, deionized water, and bovine serum was decreased by 17.0%, 29.8%, and 32.3%, respec-