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Dual motion fretting wear behaviors of titanium and its alloy in artificial saliva

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Abstract: A dual motion combined by radial and tangential fretting was achieved on a modified hydraulic fretting wear test rig. The dual motion fretting tests of medical pure titanium (TA2) and Ti6Al7Nb alloy in artificial saliva were carried out under varied contact inclined angles (45° and 60°), and the maximum imposed load varied from 200 to 400 N at a constant loading speed of 6 mm/min. The effects of the cyclic vertical force and the inclined angle were investigated in detail. Dynamic analysis in combination with microscopic examinations shows that the wear scar and plastic deformation accumulation present a strong asymmetry. The Ti6Al7Nb has better wear resistance than TA2 in artificial saliva at the same test parameters, and with the increase of inclined angle and decrease of imposed load, the wear reduces accordingly. The wear mechanisms of pure titanium TA2 and Ti6Al7Nb alloy under the condition of dual motion fretting in artificial saliva are abrasive wear, oxidative wear and delamination.

Key words: titanium alloy; fretting wear; dual motion fretting; tangential fretting; radial fretting; wear mechanism

1 Introduction

Abutment screw fracture and loosening of single and multiple fixed partial prostheses attached to external hexagonal implants are commonly encountered [1,2]. The service life of the metal devices depends upon two factors, ie, the mechanical and environmental factors, the reduction of wear under fretting corrosion [3−7]. In dental implants, fretting motion is induced by the biting force, mastication on the implant/abutment or on the abutment/ceramic crown [8]. Fretting damage would lead to toxicity, reddening and allergic reactions of the skin, inflammation of tissues.

Therefore, just as the degree of implant integration with surrounding osseous tissue is paramount to physiologic success, the degree of mechanical integration within the prosthodontic interfaces is crucial to prosthodontic success [9]. A 3-year evaluation of 16 patients with 23 single-tooth implants revealed that 57% of the abutment screws became unstable in the first year, 30% of those became unstable in the second year, and 5% of those became unstable in the third year. Only 35% of the abutment screws remained stable throughout the entire follow-up period [10].

To understand how screw loosening can occur, it is necessary to understand certain mechanical damage principles. The abutment screw and implant are joined together by the dentist to form a clamped joint. When the screw is first tightened, an initial tensile preload is generated within the screw. The ultimate effect of this preload is to place the abutment/implant assembly in compression, which will result in friction (fretting) between the screw and implant thread, the head of the screw and the abutment [11]. During the human physical activity, the normal thresholds for micro-movements at the screw−implant thread interface are very small. Those movements at the interface are hardly detectable in vivo, but fretting damages of the interface should be induced and finally cause the initial failures for the accumulation of mico-cracks and other damages [12]. Therefore, evaluation of the fretting wear behaviors of the screw−implant thread interface is very important in their application.

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There have been considerable interests in the experimental and theoretical studies on fretting behavior under various conditions. Under the contact of ball-on-flat, there are only 4 basic fretting modes, such as reciprocating or tangential, radial, rotational and torsional modes [13]. In particular, the tangential mode has been widely investigated. However, for many fretting cases in real life applications, relative motion of fretting is very complex and the damage is often induced by combined fretting modes with a superimposition of two or more in the 4 basic modes. As shown in Fig. 1(a), the fretting occurring at the screw helicoid of dental implants always combines the tangential and radial fretting modes.

Titanium and its alloys are widely used as implant materials because of their low density, good intensity, relatively low elastic modulus, excellent biocompatibility and corrosion resistance [14,15]. In this work, the complex fretting wear behaviors combined by the tangential and radial fretting modes of titanium alloy in artificial saliva of 37 °C (body temperature) in a fretting test system are studied in detail. The aim of this investigation is focused on the dual motion fretting running behaviors and its mechanisms of titanium alloy in body simulation environments.

2 Experimental

A ball-on-flat contact configuration was selected as the friction test mode. The surface of flat specimens was inclined to the horizontal direction, as shown in Fig. 1(b) [16]. Two upper clamps with the inclined angles θ of 45° and 60° were manufactured for the varied tests. Cyclic displacement between contact surfaces was measured by the extensometer. Variations of vertical force versus displacement ($F-D$ curve) of dual motion fretting were recorded as a function of cycles. The displacement and force measured from the $F-D$ curves were not real values of displacement and frictional force at the interface in the case of tangential fretting. Under an extreme condition, when θ=90°, the fretting contact situation turned to radial fretting mode; and when θ=0°, the tangential fretting mode could be obtained.

The Ti6Al4V ball with a diameter of 40 mm was used (HV 345, R_a=0.05 μm). The flat specimens with dimensions of 10 mm×10 mm×20 mm were machined from the pure titanium (TA2) and two medical titanium alloys, i.e. Ti6Al4V alloy (6.020 Al, 4.10 V, 0.168 Fe, 0.160 O, 0.043 C and balanced Ti, mass fraction, %) and Ti6Al7Nb alloy (5.88 Al, 6.65 Nb, 0.03 Fe, 0.10 C, 0.20 O, 0.07 N, 0.02 H and balanced Ti). The surfaces were polished to a roughness of 0.04 μm. The main mechanical properties of the specimens are listed in Table 1. The artificial saliva (0.4 g NaCl, 0.4 g KCl, 0.795 g $CaCl_2\cdot 2H_2O$, 0.78 g $CaCl_2\cdot 2H_2O$, 0.005 g $Na_2S\cdot 9H_2O$, 1 g urea, 100 g distilled water) was used to simulate the oral environment.

Fretting tests were performed under laboratory control conditions (temperature 23 °C; relative humidity 60%±10%). Maximum cyclic forces (F_{max}) were 200 and 400 N. To keep contact and avoid impact effect during testing, a minimum force (F_{min}) of 50 N was imposed for all tests. The speed of piston movement was controlled at 6 mm/min. The number of cycles was ranged from 1 to 10^4. Prior to the tests, all specimens were ultrasonically cleaned in acetone. The morphologies of the damaged scars were examined by an optical microscope (OM, OLYMPUS BX60MF5) and a scanning electron microscope (SEM, JSM-6610LV) after the tests.

3 Results and discussion

3.1 Kinetic behavior

Figure 2 shows the effect of the inclined angle (θ=45° and 60°) on the $F-D$ curves. At a lower inclined angle (θ=45°), the shape of $F-D$ curve was ellipse at the initial stage, as shown in Fig. 2(a). With the increase of the number of cycles, the $F-D$ curves became quasi-

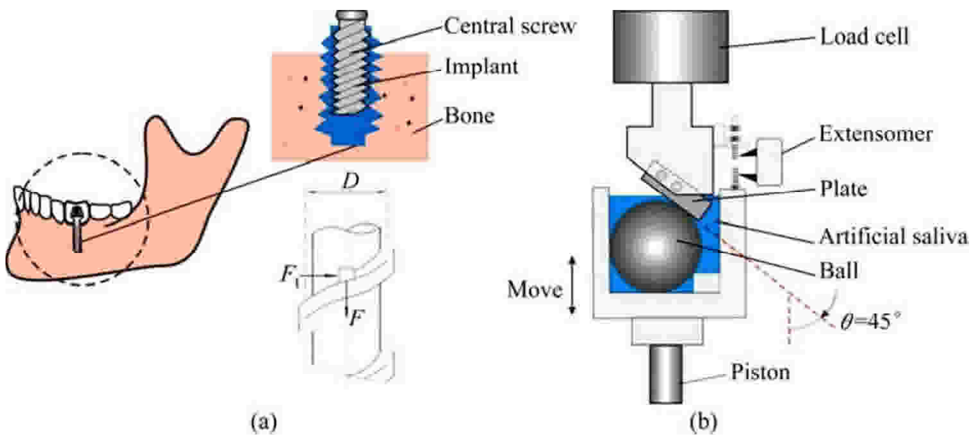

Fig. 1 Schematic diagram of dual motion fretting wear test rig: (a) Dental implant; (b) Fretting device