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Surface friction behaviour of anodized commercially pure titanium screw assemblies

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Abstract

Dental implant abutment fixation by screw requires a prescribed preload (tensile screw load) for structural and implant performance purposes. This paper investigates the effect of surface modification on the apparent frictional behaviour of commercially pure Grade 4 titanium bolt assemblies by anodizing. 4 mm screws are anodized at various anodizing voltages to control the oxide layer thickness. Fixation torque is measured along with the corresponding tensile load in the screw and used to determine the dynamic surface friction coefficient for fastening and the static surface friction coefficient for untightening. Surface hardness is measured and linked to the frictional behaviour. The reduction in the apparent frictional behaviour are presented and discussed.

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Keywords: Anodization, Screw, Friction coefficient, Titanium Grade 4

1. Introduction

Titanium dental implants are extensively used to facilitate maxillofacial function and aesthetics due to tooth loss because of disease or trauma. The tooth crown and abutment assembly are affixed to the implant usually by screw for a prescribed preload by applying an appropriate torque. The required torque to facilitate the prescribed preload is a function of the frictional surface interaction between the implant and screw. The management of the required torque to facilitate the preload has benefits for patient comfort and implant stability.

Titanium is a low-density element which can be strengthened by alloying and work hardening[1]. Commercially pure titanium has a high corrosion resistance, is nontoxic and has good biocompatibility and is therefore extensively used in biomedical applications[2].

Titanium is known for its poor tribological properties. It is susceptible to high surface friction, poor wear resistance, and low surface hardness. It is prone to cold welding and adhesion when undergoing friction[3]. Dissimilar material bolt assemblies (screw material being different from that used for the nut) is then frequently used to reduce the friction between for example fixture screw and the implant[4].

Freshly exposed titanium reacts with oxygen in ambient conditions in the atmosphere to form a tough titanium dioxide (TiO_2) layer that protects the material against corrosion[4]. Anodizing is a process where the thickness of the oxide layer can be chemically manipulated[5]. It is an electrolytic process whereby an oxide layer of specific thickness is produced on the material by means of essentially controlling the anodizing potential difference[6]. The increased thickness of the oxide layer usually increases resistance against corrosion[7].

The anodizing process can also be used to harden the surface of titanium, known as hardcoating. It reduces galling and increases abrasion resistance[8]. Titanium dioxide has an exceptionally high hardness value[9]. The presence of alloying elements alters the response of the material to the anodizing process but can usually be applied to most grades of titanium[7].

An increased preload in the afore mentioned implant assembly can reduce the failure rate of titanium dental implants as micro spaces between the abutment and implant is reduced which will reduce tissue growth, and therefore the associated complications, into those spaces. Loosening of the assembly by means of dynamic loading can also be reduced by increasing the preload force.

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The aim of this investigation is to evaluate the effect of anodization on the surface friction coefficient of bolt assemblies manufactured from commercially pure Grade 4 titanium. The anodizing voltage is varied from 10V to 100V in increments of 10V. Each assembly is torqued to 2 N.m. at a constant rotational velocity. The screw geometry is kept constant throughout the duration of the investigation. A contact thread length of 10 mm (14.3 screw threads) is used resulting in a theoretical contact area of approximately 69.2 mm^2 between the screw and nut.

2. Experimental procedure

2.1. Materials

Surface friction tests are conducted on Grade 4 commercially pure titanium screws and nuts. The certified mechanical properties and chemical composition of both screws and nuts are presented in Table 1.

Table 1: Mechanical properties and chemical composition of screws and nuts

Mechanical properties (screw/nut)		Chemical composition (screw/nut)	
Tensile strength (MPa)	685/763	C (%)	0.01/0.05
Yield strength (MPa)	560/646	N (%)	0.01/0.006
Elongation (%)	22/20	Fe (%)	0.20/0.125
Hardness (HV)	NA/263	H (%)	0.002/0.003
		O (%)	0.30/0.33
		Ti (%)	Remainder

2.2. Sample preparation

M4 screws are manufactured from Grade 4 titanium by threading on a CNC lathe. The nuts are manufactured by performing a tapping process on a CNC milling machine.

The screws are anodized using 20% sulfuric acid (H_2SO_4) solution as an electrolyte at ambient temperature. A variable voltage is applied across the electrodes using an analogue dc power supply. The voltage is increased at a rate of 1V/sec until the required output voltage is acquired. The sample is anodized at the set output voltage for 3 minutes +/- 5 seconds. Only the screws are anodized with voltages varying from 0V to 100V in increments of 10V. The distance between the centerlines of the screw and the two cathodes is kept constant at 20 mm with a Cathode/Anode ratio of 14.6/1. The anodizing fixture used is illustrated in Fig 1.

Before the sample is anodized, it is rinsed in acetone (C_3H_6O) and then cleaned using a 40% nitric acid (HNO_3) solution in an ultrasonic bath. Once the screw is anodized, the surface is rinsed using deionized water. Prior to conducting surface friction coefficient testing, each sample is rinsed using acetone and then rinsed using deionized water.

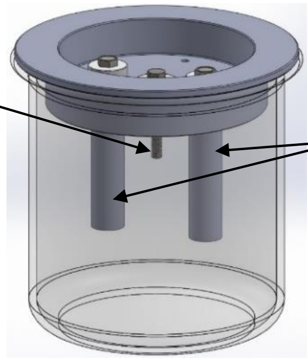

Fig. 1. Anodizing fixture

2.3. Measurement

A dedicated fixture was used to measure the friction between the screw and nut. Each screw is tightened to 2 Nm from an initial zero load. The tightening procedure induces a tensile load in the screw which is measured by a loadcell. The applied torque is measured by an instrumented torque wrench. Tensile load and torque is measured simultaneously. A rotation of approximately 300 degrees was required to obtain 2 N.m. The experimental fixture is presented in Fig 2.

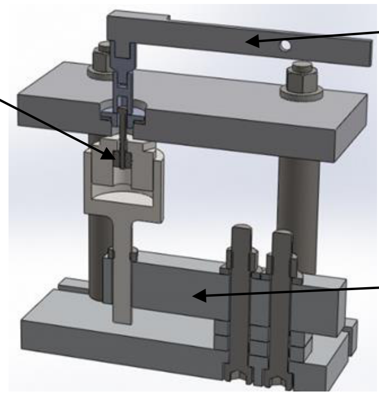

Fig. 2. Section view of fixture used to measure preload

2.4. Sample analysis

The surface friction coefficient (μ_{th}) is calculated by using the Motosh equation[10] :

$$\mu_{th} = \frac{\frac{T_{Thread}}{F} - \frac{P}{2\pi}}{0.577 d_2} \quad (1)$$

Where T_{Thread} represents the torque, F is the tensile load on the screw, P is the pitch of the thread (0.7 mm) and d_2 is the basic pitch diameter of the thread (3.545 mm). The data measured is filtered using a 5^{th} order polynomial equation.

Hardness tests are performed using a Vickers hardness tester and surface microscopy is performed by a scanning electron microscope.