ELSEVIER

Tribology International 39 (2006) 266–273

TRIBOLOGY INTERNATIONAL

www.elsevier.com/locate/triboint

Effect of age on the friction and wear behaviors of human teeth

J. Zheng, Z.R. Zhou*

Key Laboratory of Advanced Technologies of Materials of Ministry of Education, Tribology Research Institute, Southwest Jiaotong University, Chengdu 610031, China

Received 12 December 2003; received in revised form 8 January 2004; accepted 13 September 2004
Available online 3 March 2005

Abstract

Friction and wear behavior of human teeth at different ages against titanium alloy have been investigated using a reciprocating apparatus containing an artificial saliva solution. Human teeth at different ages of 8, 18, 35 and 55 years old were selected for tests. Both hardness and distribution of enamel rods on the occlusal surface, two of factors most important to tribological behavior of human teeth, are close to the age of teeth. It is found that not only the evolution of friction coefficient but also the wear behavior changes between teeth of different ages. Delamination and ploughing mechanisms are dominant for wear of human teeth, and more severe wear is observed for the primary and the permanent teeth at the old age accompanied by remarkable fluctuation in the friction coefficient. Compared with the primary teeth and the permanent teeth at the old age, the permanent teeth at the young and middle ages have better wear-resistance.

Keywords: Human teeth; Age; Titanium alloy; Friction and wear

1. Introduction

The crown of human tooth comprises outer enamel and inner dentin. Enamel, whose basic structure element is hydroxyapatite crystallite, is the hardest tissue in human body because of the existence of enamel rods [1]. Enamel has better resistance against mastication attrition than that of dentin. For both primary teeth and permanent teeth, wear occurs in the occlusal surface of tooth crown during masticating process [2,3]. However, excessive wear could reduce mastication function, influence the growth of children's face or result in some oral disorders, such as high sensitivity of tooth to normal irritations, temporomandibular disorder, etc. [4–6]. Therefore, it is very necessary to study the tribological property of human teeth, aiming to reveal the wear mechanism of teeth and how significant the wear is with increasing ages so as to help the clinical treatment for teeth and develop new dental restorative materials to protect human teeth.

Wear of human teeth is an extremely complex process that involves mechanical, thermal and chemical reactions. Many of the factors, such as ageing, various pathologic changes, and so on, can affect the wear of human teeth [7–10]. Nowadays, many studies have been conducted on the wear of restorative materials, such as ceramic, composites, and metallic alloys, while the studies on wear of human teeth are mainly focused on clinical observation. Few studies have been carried out to reveal the effect of age on the friction and wear behaviors of human teeth. In our previous work, human teeth against different dental restorative materials in the dry and artificial saliva conditions have been investigated [11]. Friction and wear behavior on the enamel and dentin of the same tooth has also been analyzed [12].

In this paper, in vitro wear tests have been conducted on human teeth against titanium alloy. The main objective is to understand the friction and wear behaviors of human teeth at different ages, and help the dentists select appropriate dental restorative materials with better friction matching properties.

2. Materials and methods

2.1. Sample preparation

Flat samples used in this study were freshly extracted human teeth without caries. The teeth were then placed in

* Corresponding author. Tel./fax: +86 28 87600971.
E-mail address: zrzhou@home.swjtu.edu.cn (Z.R. Zhou).

0301-679X/$ - see front matter © 2005 Elsevier Ltd. All rights reserved.
doi:10.1016/j.triboint.2004.09.004

distilled water at 4 °C to avoid dehydration before sample preparation. Forty mandibular second molars (M_2), including 10 primary teeth and 30 permanent teeth were used. Primary teeth were obtained from different children of 8 years old. Permanent teeth at young, middle and old ages came from people of 18, 35 and 55 years old, respectively.

Every tooth was cut into two halves along the buccolingual division line, using a diamond saw. The half of lingual side was then embedded into a steel-made mold with self-setting plastic (10×10×20 mm in size) to obtain flat samples with the occlusal surface facing up. All the mounted samples were ground and polished under water-cooling condition. Detailed preparation of teeth sample was done according to the methods that have been described in our previous work [12]. Only 0.2–0.3 mm was ground and polished off, aiming to keep the obtained surface similar to the original occlusal surface of teeth in mouth. After polishing, the samples were stored in distilled water at 4 °C as well. The teeth were dehydrated partially during preparation, but efforts were made both to shorten the dry time and to keep the preparation time approximately the same for each sample.

The average roughness, R_a, of the flat samples was measured to be 0.20 μm using a high sensitive surface profilometer (TALYSURF6, England). A titanium alloy ball (C 0.043%; Al 6.020%; H 0.011%; O 0.160%; V 4.100%; Fe 0.168%; Ti the balance) with hardness 350 HV and of 40 mm in diameter was used as a counter ball during the friction-wear test. All samples were cleaned by alcohol before testing. Due to excellent biocompatibility, pure titanium and titanium alloy are often used as dental materials in clinic recently. Therefore, pure titanium was chosen as counter sample in our previous study. However, compared with pure titanium (240 HV), the Vickers hardness of titanium alloy matches that of human tooth enamel better [13]. And in terms of the evolution and stable value of the friction coefficient and the worn surface morphology and wear scar depth, the enamel/titanium alloy pair was similar to the enamel/enamel pair [13].

2.2. Microhardness characterization

Microhardness of contact surface of human teeth was tested before wear test. 10–20 indentations under a load of 50 g were produced for each polished surface, using a Vickers diamond indenter in a microhardness tester (MVK-H21, Japan). The lengths of indentation diagonals were measured under optical microscopy immediately after indenting and converted to microhardness automatically. The whole process of indentations was completed within 40 min at 25 °C. Effort was also made to keep the indentation time approximately the same for each sample.

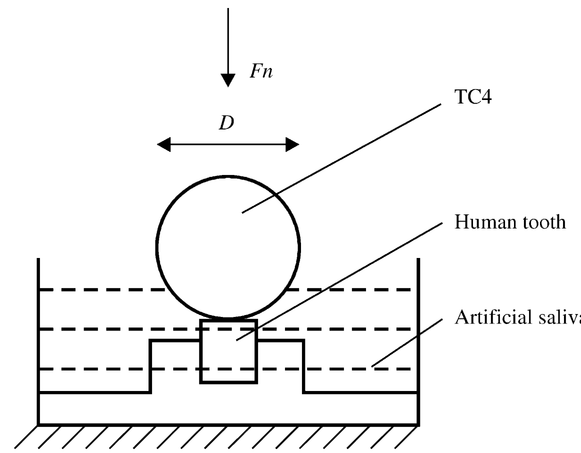

Fig. 1. Friction and wear test rig.

2.3. Friction and wear test

To better simulate real wear condition of human teeth, reciprocating sliding wear tests with artificial saliva bath lubrication were conducted in a ball-on-flat configuration instead of a traditional pin-disc test rig (Fig. 1). The choice of two-body in vitro wear test parameters was based on clinical experience and literature. A normal force of 20 N was imposed in tests as the magnitude of masticatory force in mouth ranges from 3 to 36 N during chewing process [2]. According to Hertzian theory, the Hertzian contact diameter, 0.350 mm, and the associated mean contact pressure, 208.0 MPa, were calculated [14]. Young's modulus and Poisson's rations used for this calculation were 113 GPa and 0.30 for Ti alloy [15], and 94 GPa and 0.28 for human enamel [16,17], respectively. In addition, reciprocating amplitude of 500 μm and frequency of 2 Hz were used for all the tests. Tests up to 5000 cycles were conducted with an interval of 30 min at every 1000 cycles. The normal force was discharged and the contact surfaces were carefully cleaned by artificial saliva during the period of the intermittence. The artificial saliva was prepared according to Fusayama's guidelines with Holland's modification [18,19] and its composition is listed in Table 1.

To avoid individual difference and assure the repetition of experimental results, 10 human tooth samples were tested for each age band. Variations of tangential force vs reciprocating displacement and coefficient of friction were recorded automatically as a function of cycles. Wear marks and their profiles were examined and analyzed by laser confocal scanning microscope (OLYMPUS OLS1100, Japan). Wear was determined from maximum wear depth, which was the lowest point in the nominal shape of the wear

Table 1
Composition of artificial saliva

NaCl	KCl	$CaCl_2 \cdot 2H_2O$	$NaH_2PO_4 \cdot 2H_2O$	$Na_2S \cdot 9H_2O$	Urea	Distilled water
0.4 g	0.4 g	0.795 g	0.78 g	0.005 g	1 g	1000 ml