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A representative ex-situ fretting wear investigation of orthodontic arch-wire/bracket contacts

Cezary Rapiejko[a,c], Siegfried Fouvry[a,*], Brigitte Grosgogeat[b], Bogdan Wendler[c]

[a] LTDS (UMR 5513), Ecole Centrale de Lyon, Lyon, France
[b] LMI (UMR 5615), Faculty of Odontology, University of Lyon, Lyon, France
[c] Technical University of Lodz, Lodz, Poland

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ABSTRACT

Recent studies show that resistance to friction and wear between the arch-wire and the bracket are of great importance for the quality of orthodontal treatment. To optimize these phenomena specific surface treatments have been developed, but a major difficulty is the methodology for comparing and improving the given palliatives. A specific ex-situ fretting test has been developed which permits the micro-slidings generated by the occlusion movements to be superimposed on macro-slidings generated by the teeth displacement.

In this study the friction force between brackets and arch-wires during combined macro-/micro-slidings has been investigated. Various stainless steel bracket/arch-wire contacts have been analyzed. The wear and friction properties of different PEPVD deposited coatings such as SiC and SiN have been studied under dry and wet artificial saliva conditions.

1. Introduction

Friction and wear phenomena in oral arch-wire bracket contacts are crucial for the quality of orthodontal treatment (Fig. 1). Indeed, high friction coefficient induces overstressing, which can damage the periodontal ligaments (the entire dentition is essentially joined to the surrounding bone through "springs" which form the periodontal ligament). This generates fastidious and expensive clinical complications and for the worst cases (and specific patients) it could activate a periodontal bacteria attack which, by destroying the periodontal ligaments, would generate an irreversible decohesion of the teeth [1].

Moreover, friction will induce wear of the brackets and arch-wire materials which mainly consist of TiNi (Nitinol) alloy and stainless steels. This wear favors the spread of heavy metals like nickel through the body.

Good biomaterials should not only possess the required biocompatibility, bioacceptability and hemocompatibility, but also good tribological and mechanical properties. None of the materials used up to now can fulfill all the above-mentioned requirements. This statement is true also for bio-compatible materials like titanium or stainless steel, which exhibit very poor tribological behavior.

During the past decades a rapid development of the plasma enhanced physical vapour deposition (PEPVD) techniques has been observed and the surface properties of numerous materials have been modified to a great extent with use of these methods. For example, in the paper [2] a series of Si-based covalent-bonded chemical compounds Si_xC_y, $Si_xC_yN_z$ and Si_xN_z have been deposited onto the surface of specimens made of AISI 304 and AISI 430 (austenite and ferritic stainless steels, respectively) as well as on the surface of monocrystalline Si wafers. All the specimens have been ultrasonically cleaned in acetone. The final cleaning with use of glow discharge in Ar plasma at the pressure 3 Pa has been executed in the reactor just before the deposition. The Si_xC_y or Si_xN_z coatings have been deposited by a reactive magnetron sputtering technique at the substrate temperature 373 K at a permanent bias potential −50 V in a reactive atmosphere 59% Ar + 41% C_2H_2 or 55% Ar + 45 N_2, respectively. Deposited coatings exhibit outstanding properties, like excellent resistance to chemical and electrochemical corrosion, as well as a good wear resistance and high hardness. Moreover, in the domain of medical applications, the SiC coating is regarded as a biomaterial having the best hemocompatibility widely used for manufacturing cardiovascular implants as, for example, heart valves that contact human blood for a long time [3]. Due to these characteristics of the SiC or SiN coatings the properties of different substrates can be modified to a great extent. For example, the interaction between the wear debris of arch-wires or brackets generated during friction and the human body can induce severe diseases like metalosis and other dysfunctions of the body. It is therefore of great

* Corresponding author. Tel.: +33 04 72 18 65 62; fax: +33 04 78 33 11 40.
E-mail address: siegfried.fouvry@ec-lyon.fr (S. Fouvry).

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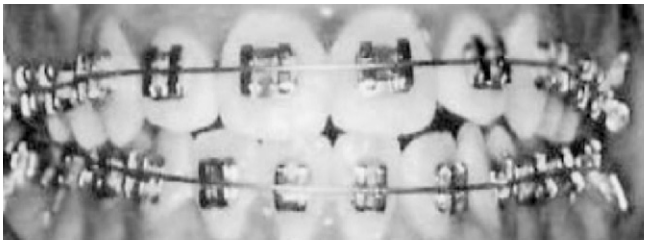

Fig. 1. Orthodontic materials in use.

importance to elaborate new palliatives to improve the wear behavior of artificial biocomponents. Some particular hard coatings have been shown to be pertinent for such applications [4]. It looks like that hard magnetron sputtered Si_xC_y or Si_xN_z coatings can decrease also the wear and the amount of debris particles [5,6].

Surface roughness, contact geometry and the materials properties influence the friction and wear behavior [7–10]. In the case of orthodontic materials where the contacting parts are the arch-wire and bracket, the contact configuration is very complex. The arch-wire inserted into the bracket produces various random contact points [11–13]. To investigate this kind of friction node and evaluate the potential interest in SiC or SiN coatings for such an application a specific experimental methodology has been developed.

2. Materials and methods

2.1. Specimens

Commercial arch-wire (GAC REF 03-622-99) and bracket (GAC 022/L4-5 0T 0A) systems were tested. All tests were carried out at loading conditions as close as possible to the real ones. In order to increase the wear kinetics the first step during the tests was made under “dry” conditions (without use of artificial saliva). Then the conditions of the test have been changed and the investigations have been conducted under immersion in “artificial saliva” environment (with use of artificial saliva – “Fusayama” – Table 1). A peristaltic pump permits a continuous circulation of the artificial saliva in the fretting bath maintaining a constant 37 °C temperature. All the studied tribo-couples involve an AISI 304 stainless steel as the substrate material (Table 2). Some of the samples were coated with SiN and SiC layers. The studied arch-wire/bracket contact configurations are compiled in Table 3. The surface parameters are compiled in Table 4. The SiC coating is slightly thicker than the SiN coating. The surface roughnesses of the studied surfaces are similar around 0.3 μm.

Table 1
Composition of artificial saliva by Fusayama.

NaCl (g/l)	KCl (g/l)	$CaCl_2 \cdot 2H_2O$ (g/l)	$Na_2S \cdot 9H_2O$ (g/l)	$NaH_2PO_4 \cdot H_2O$ (g/l)
0.400	0.400	0.906	0.005	0.690

Table 2
Chemical composition of the steel AISI 304 (in wt.%).

C	Mn	P	S	Si	Cr	Ni
Max 0.07	Max 2	Max 0.045	Max 0.03	1	17/19	9/11

Table 3
Definition of the studied contact configurations.

Arch-wire	Bracket	Symbol
SS	SS	SS–SS
SS	SiC	SS–SiC
SS	SiN	SS–SiN
SiN	SiC	SiN–SiC

SS: stainless steel.

Table 4
Surface parameters of the studied arch-wires and brackets.

	SS	SiC	SiN
Micro hardness ($HK_{0,1}$)	401	1210	1420
Coating thickness (μm)	–	3.5	2.5
Surface roughness on arch-wires, Ra (μm)	0.3	0.25	0.28

2.2. Test conditions

The multi-point frictional interaction observed during the experiments between the arch-wires and the brackets makes the tribological analysis very complex. Moreover in-situ analyses confirmed a complex loading path combining low frequency (0.5 Hz) occlusion movements with very slow macro-slidings induced by the teeth’s displacement. Finally the saliva promotes tribooxidation phenomena and interacts both the friction and wear behavior. Hence the understanding and quantification of such a tribological system requires the development of a specific and original experimental methodology.

All the tests were carried out with use of a specially designed test system combining small reciprocating sinusoidal movements with simultaneous slow linear movement simulating the global tooth displacement (Figs. 2 and 3).

Samples were fixed on specific holders designed for this purpose. The arch-wires were attached to the moving part whereas the bracket was stuck to the bottom holder using resin. The whole contact system is presented in Fig. 3. Before mounting in the holders the samples and materials were prepared according to the following procedure. First, the couple to be tested was cleaned in methanol in an ultrasonic bath for 5 min. Afterwards, both parts of the couple were dried for 4 h, after which the mass of each part was measured. Next, the samples were fixed to the holders and the test was carried out. After the test the samples underwent the same cleaning, drying and mass measurement procedure.

The experimental set-up is shown in Fig. 4.

Similar loading conditions have been imposed for all studied tribo-couples. The normal force was kept constant at 5 N. The cho-

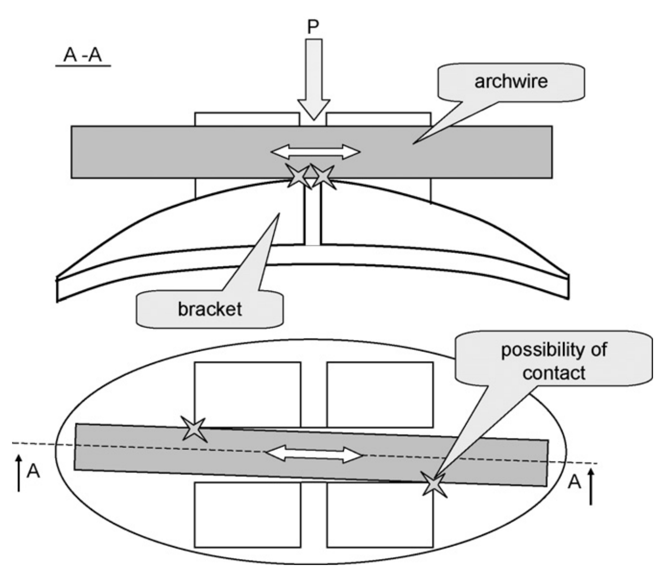

Fig. 2. Scheme of the multi-point frictional interaction in the tribo-contact arch-wire/bracket.