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Tribological study of oral care silica

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ABSTRACT

This study focuses on the effect of mechanical parameters for a better understanding of oral care silica tribological behavior. Reciprocating motion tests were performed with variable parameters (toothbrushes design, load, brushing speed, with and without silica slurries). The analysis of the tests is based on the third body concept. The flows of third body were evaluated in-situ and post-mortem related to the evolution of the friction coefficient. Clues to understand the mechanisms involved are given, showing the multi-scales and multi-physical aspects of the problem.

1. Introduction

Teeth are usually cleaned by using toothpaste, consisting of abrasive silica, active agents, organic and inorganic thickening agents in a carrier fluid, with a filament based toothbrush. The four terms attrition, abrasion, abfraction and erosion are usually used in the dental literature for describing the wear of teeth and dental materials. Attrition describes wear at sites of tooth to tooth contact; abfraction refers to loss of enamel and dentine as a result of cracks formed during tooth bending; erosion is used to describe material loss attributed to chemical effects; abrasion is used for wear at non-contact tooth/tooth sites and also for tooth brushing. It is assumed that normal tooth brushing can cause dentin abrasion but not enamel abrasion over lifetime; therefore dentin is often taken into account in the different studies on toothpaste abrasivity. To evaluate abrasivity during brushing, many different techniques have been used [1–8], i.e. the radioactive dentin abrasion (RDA) method, weight and volume loss techniques which are quantitative techniques, measuring the amount of abraded material removed as well as profilometer and light reflexion techniques, which are qualitative techniques measuring the roughness of the abraded material.

Most of the studies had focused on wear results and which wear mechanism produces a specific damage. The complexity of the tooth contact had led to adopt over the years more or less complex test types [9–11]. Some investigators study contacts with complex movement more similar to what happens in the mouth, using cycles with complex loads and paths attaining different wear types. But it remains almost impossible to extrapolate or compare results obtained with different equipment. The choice of the type of contact, the relative movement and the operating variables is also complex, especially as the mechanisms involved in the cleaning of teeth and toothpaste abrasivity are not yet well understood despite various measurements of wear performed during the last 25 years [3,4,9,11].

The effectiveness of brushing is related to multiple key parameters: mechanical parameters such as size, shape and hardness of the abrasive granules, brushing load and speed, stiffness [12] and orientation of the brush; chemical parameters such as pH of both toothpaste and saliva and toothpaste actives (surfactants). There is, however, no clear understanding of how these parameters affect cleaning effectiveness.

The aim of the present work is to investigate which phenomena could be involved in the tooth cleaning, thus in the detachment of dental plaque, as a first step for a better understanding of the tribological behavior of oral care silica. The tribological approach, based on the third body concept, gives a method of interpretation of the contact dynamics by taking into account the role of the mechanism, the first bodies and third body, to analyze the oral silica behavior.

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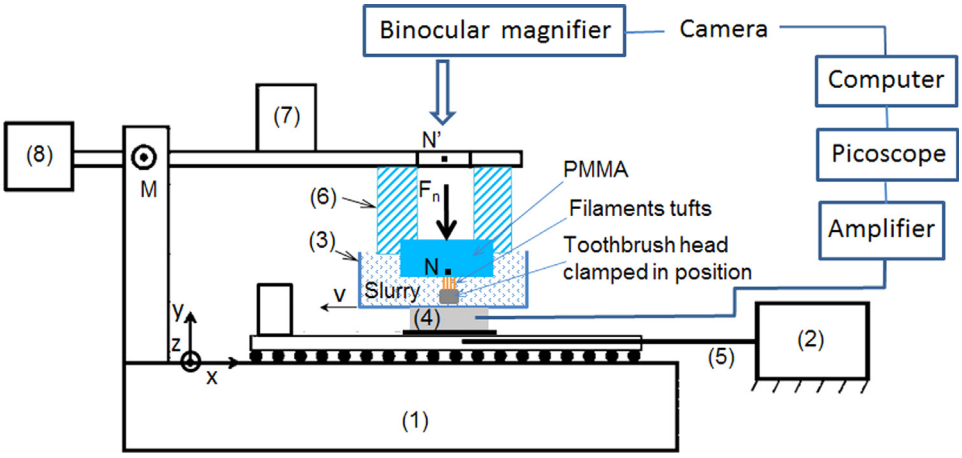
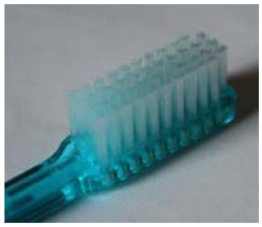


Fig. 1. Schematic representation of the test bench.

Table 1
Brush characteristics.

Brush type	Oral-B P40	Duopole
		
No of filaments per tuft	30	22
No of tufts	43	36
Total number of filaments	1290	792
Filament length (mm)	10	10
Filament diameter (mm)	0.234	0.236
Filament type shape	Round (Fig. 2a and b)	Flat or slightly in hollow (Fig. 2c and d)
Filament material	Nylon	Polyester (PolyButylene Terephthalate)

2. Experimental details – material and methods

Reciprocating motion tests are performed for the parametric study. The tribometer used is composed of three parts (Fig. 1):

- a fixed part connected to the ground composed of a frame (1) and a motor or a crankshaft/rod device (2),
- a part, composed of a container (slurry+toothbrush) (3), its support and the piezo transducer (4), that can translate along the *x*-axis in relation to the frame via a screw-nut system (5) driven in rotation manually or by the motor,
- a part composed of the flat transparent sample, its support (6), the weight (7) and a counterweight (8) The weight of assembly ((6)+flat sample) is counterbalanced by (8) in order to apply the force only with the weight (7). This part is free from rotation around the *z*-axis at point M. The normal force Fn is applied at point N by installing a chosen weight on the lever arm in the middle of the distance between the arm's axle M and N′.

The toothbrush head is clamped in position and the fluid/particle mixture fills the container (3) and covers completely the toothbrush.

The flat sample is acrylic plate, Polymethyl Methacrylate (PMMA), used as a substitute for human dentine. The supplier of the PMMA is Perpex from Lucite. It has been moulded and the Rockwell hardness is 102 (ISO 2039-2, scale M). The PMMA sample is clamped then loaded against the toothbrush head. PMMA is transparent and thus the contact zone is viewed through the PMMA, via a binocular magnifier and a camera, to examine third body flows.

The system allows the load to be distributed homogeneously on the whole brush head/PMMA contact.

Standard toothbrushes consisting of tufts of filaments are used in the tests to study particle motion and the effect of the type of the particles, the load and speed. Two experimental toothbrush types, Oral B and Duopole (2 different designs) are used. Details of the tuft configurations, filament lengths, diameters and material for the brushes used during testing are shown in Table 1, Fig. 2. Loads and brushing speeds choice is based on measurements taken during in vivo experiments (using instrumented toothbrush), from literature and from the norm ISO 11609:2010. Thus 7 loads values ranged from 1.5 to 5 N and 4 brushing speeds from 5 to 30 mm/s. A speed of less than 1 mm/s has been tested to establish the effect on particle entrainment (visualization tests performed manually). The total length of the track is 12 mm which is realistic value. Four experimental slurries (Table 2), prepared according to the protocol described in ISO11609:2010 and containing water, glycerin, carboxymethyl cellulose and abrasive, were provided by Solvay Silica. Table 3 shows the characteristics of the abrasives: three silica powders with various abrasive level and one of calcium pyrophosphate, ISO11609:2010 abrasive reference. The particle size distribution has been measured by laser method. The median diameter