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Abrasive and sliding wear of resin composites for dental restorations

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ABSTRACT

The aim of this work was to study the abrasive and reciprocating sliding wear resistance of four commercial resin composites for dental restorations. Resin composite samples were divided into four groups considering the different materials and then separated for compressive, abrasive and sliding tests ($n=10$). Micro-abrasion tests were performed against a stainless steel rotating ball on 3 N normal load for 300 revolutions in the presence of a suspension containing a commercial whitening and abrasive toothpaste. Reciprocating sliding ball-on-plate friction tests were performed against an alumina ball on 20 N normal load at 1 Hz in the presence of artificial saliva at 37 °C for 30 min. The wear volume was evaluated for the different groups of resin composites and correlated with their mechanical properties and inorganic composition in terms of size and volume percentage of filler particles. Resin composites with high volume content of inorganic fillers (82 wt%) consisting of micro particles (0.1–2.5 μm) combined with small nanoparticles (20–60 nm) revealed the most proper mechanical and tribological response. The dominant wear mechanisms consisted on fine micro-scale abrasion for abrasion tests and surface fatigue and abrasion for reciprocating sliding tests.

1. Introduction

The development of resin composites as dental restoration materials came through the need for materials that mimic tooth structures. However, wear of these composites still remains as a major clinical problem. Regarding previous studies, the wear resistance of such materials mainly depends on the size, distribution, mechanical properties and content of inorganic fillers [1–10].

Since the introduction of resin composites, changes have been made on the size and development of inorganic fillers as well as on the synthesis of polymers for the organic matrix of restorative resin composites [2]. The size of the inorganic particles has been decreased down to nano-scale dimensions. The wear resistance of the resin composites has been improved due to the mixture of high content of particles at micro- and nano-scale associated with different properties [2,3]. The addition of inorganic particles with higher hardness to a matrix with lower hardness allows to improve the abrasion resistance of the restorative material. Also, mechanical, thermal and optical properties of the dental restorations are considerably influenced by the content and size of the inorganic fillers [2,3]. For instance, the increase of the inorganic content positively affects the mechanical strength of the material. Also, the high inorganic content results in the decrease of the organic matrix volume that leads to a reduction of the polymerization shrinkage and coefficient of thermal expansion of the material [2,3]. At the end of 80's, resin composites were developed containing inorganic particles with size of about 1 μm along with a content of colloidal silica with mean size of 40 nm [2]. The improvements in particle size resulted in resin composites containing two different kind of particles concerning chemical composition: particles with size ranging from 0.4 up to 10 μm; and nanometric particles with dimensions at 20–40 nm. These materials are called micro- or nano-hybrid resin composites depending on the size and content of micro- or nano-particle [2,3]. Also, such resin composites are named universal. Commercially, it is difficult to distinguish between the micro- and nano-hybrid once the microstructure and mechanical properties of both tend to be similar [2,3].

In fact, the size of the inorganic fillers plays an important role on the wear resistance of the material. In vitro wear tests carried out in previous studies have revealed that composites containing spherical particles with 0.2 μm in diameter showed greater wear

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resistance compared with composites that contain larger inorganic particles [13]. Additionally, an important point to mention is the mechanical properties of the particles once fragile inorganic particles can fracture or pulled out from the surface causing rapid abrasion of resin composites [10]. Other previous studies indicated that the wear of resin composites decreased as the volumetric percentage of inorganic particles increases [13,14]. The space between particles exposing the organic matrix also influences the physical properties and wear behavior of resin composites [10,13,14]. Previous studies reported that the critical distance between particles in the microstructure is between 0.1 and 0.2 μm in order to protect the material against wear [10]. The composition of the polymer matrix is also an important factor that affects the wear rate of resin composite. So, for example, the higher wear resistance associated with UEDMA/TEGDMA monomer assembly may be related to their higher degree of conversion than for BisGMA/TEGDMA [10].

Despite the great development of resin composites in recent years, the abrasion process resulting from chewing and brushing of the teeth is still a clinical issue leading to failures and premature restoration replacement [4–10]. Regarding the brushing process, the toothpaste can accelerate the process of abrasion depending on the properties of abrasive particles present in its composition [6,8]. The wear process is the result of a combined action of sliding contact and three-body abrasion [10,11]. Thus, the development of toothpaste follows the properties of the enamel and resin composites, maintaining the goal of removing the dietary residues and oral biofilm [6]. A limit of abrasiveness was established considering the hardness of dental structures, which is known as Relative Dentin Abrasion (RDA) [7]. RDA is based on an in vitro method which determine the ability of the toothpaste to remove the dentin, depending on the size, content and properties of abrasive particles [8].

The oral environment has an extremely important role in tribological behavior of both natural and artificial dentition. Cracks can occur in enamel due to overload, progressive wear or trauma causing exposure of dentin. That consequently can accelerate the wear rate. The wear processes on dental restorative materials are complex and typically include phenomena of friction, adhesion, abrasion, corrosion and fatigue, which cause the loss of surface of artificial materials present in the mouth [10,11]. The major issue in the use of resin composites is related to an inadequate wear resistance on posterior restorations, due to the higher load magnitude in this zone, which consequently results in the loss of anatomical shape [10,11].

The aim of this work was to study the abrasive and reciprocating sliding wear resistance of four commercial resin composites for dental restorations under conditions that can be found in the mouth. Additionally, compressive tests were performed to be correlated to the wear resistance.

2. Materials and methods

2.1. Preparation of the specimens

In this study, four groups of commercial resin composites for dental restorations were selected: Grandio®So (Voco, Germany); Ceram-X™ (Dentsply, Germany); Clearfil™ (Kuraray, Japan) and Natural Elegance® (Henry Schein, USA). Those commercial materials are identified in Table 1 as resin composites A–D. Detailed information is given by the manufacturers concerning their organic and inorganic composition, also including size of the inorganic particles and respective volume content.

Resin composite specimens were processed accordingly to the instructions given by the manufacturers. Cylindrical specimens (6 mm in diameter and 4 mm in height) were produced for compressive tests while square specimens ($10 \times 10 \times 2$ mm) were produced for tribological tests. Specimens were shaped by a single operator using a Teflon split-mould and then light-cured using Coltolux 75 (Coltène/Whaledent, Altstatten, Switzerland) curing device at 1000 mW/cm^2 for 40 s on top and bottom surfaces. Then, the specimens were taken out from the Teflon mold and additionally light-cured for 40 s on each cylindrical side surface. After polymerization, specimens were polished with SiC papers down to 4000 Mesh followed by finishing with 1 μm diamond paste. Finally, specimens were ultrasonically cleaned in distilled water for 15 min and then immersed in distilled water for 24 h.

2.2. Compressive strength tests

Compressive strength tests were performed at 23 °C using a universal testing machine (Instron 8874, MA, USA) at a crosshead speed of 1 mm/min. The universal testing machine was fitted with a 25 kN load cell and electronically controlled using specific software (Instron Bluehill 2.6, USA). Before mechanical test, the specimens were immersed in distilled water for 24 h. Specimens ($n=10$) were then positioned vertically on the testing machine base and subjected to axial compressive loading up to fracture. The mean values of compressive strength were obtained. The tests were recorded using Instron Bluehill 2.6 software and the compressive strength values were calculated from the equation F/pr^2, where F is the maximum load at fracture and r the radius of the cylindrical specimen.

2.3. Microabrasion tests

Micro-scale abrasion tests were performed using a TE-66 micro-scale abrasion equipment (Phoenix Tribology Ltd, UK) [19,25]. Resin composite square specimens were mounted on an aluminum plate which was attached to the micro-scale abrasion machine (Fig. 1). The abrasive suspension consisted in distilled water containing whitening commercial toothpaste (RDA 200) in a proportion 2:1 in weight. The abrasive suspension was maintained homogenized during the tests with the placement of the suspension container on a magnetic stirrer. Specimens tested in distilled water were used as control group. The micro-scale abrasion tests were performed on 3 N normal load against a stainless steel ball (ASTM 52 100) with 25 mm diameter, hardness mean value at 750 HV, rotating at 60 rpm for 600 revolutions. Five experiments were performed per test condition.

After the tests, specimens were removed from the apparatus and ultrasonically cleaned in distilled water. The diameter of the resulting abrasion scars was measured by optical microscopy and scanning electron microscopy. The wear volume was calculated using the standard technique for measuring the wear scar of a spherical geometry [12], i.e. assuming that it reproduces the geometry of the ball (with radius R); the wear volume (V) may then be calculated by measuring the crater diameter (b):

$$V \approx \pi b^4/64R \quad for\ b \ll R$$

2.4. Reciprocating wear sliding tests

Resin composite specimens were placed in an electrochemical cell and immersed in fresh Fusayama's artificial saliva solution at pH of 5.5 and 37 °C (see Table 2).

Reciprocating wear sliding tests were performed against an alumina ball (Goodfellow, UK) of 10 mm diameter at a 20 N normal load, 1 Hz, and a linear displacement amplitude of 2.5 mm for 90 min using a tribometer (CETR UMT2 Multi-specimen test system, Bruker, USA). The tribometer was coupled to the UMT test