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Wear and friction characterisation of some restorative dental materials

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Abstract

Dental wear is a complex field of tribology study, due to the combination of wear mechanisms, such as attrition, abrasion, erosion, and abfraction. The aim of the work was the study the wear in dental restorative materials, using a reciprocate tester in order to simulate the attrition in the oral cavity. This phenomenon occurs when sliding tooth against tooth, which generates considerable wear in the area of dental occlusion in the closed phase of mastication, and in the presence of parafunction such as bruxism. The experiments were performed employing ceramic (Ceramco 3), dental silver and, composite (Filtek Z350 XT) as restorative materials and nickel-chrome alloy as counter-body, using a reciprocating tribometer manufactured according to some parameters of standard ASTM G133-05. The geometrical configuration was a sphere on a flat plane. The experimental results obtained were volume loss and coefficient of friction of the different dental restorative materials. Also, wear mechanisms like plastic deformation, cracks, and delamination between others could be identified.

1. Introduction

In the human oral cavity are 32 secondary teeth (permanent) whose main function is to crush food; however, they are also important for speak [1,2]. The tooth can be separated into two regions (see Fig. 1), the visible zone composed of the dental crown and the neck, where we can find the dental enamel known as the strongest tissue within the human body [3,4], and the non-visible area, composed of dentin, pulp, bone, etc.

The non-carious dental wear is a multifactorial process based on a physiological and pathological factor, for example during the movement that is made when moving the mouth, when ingesting products such as food or drinks, brushing teeth and, in some cases, caused by parafunctions such as bruxism or thegosis [5].

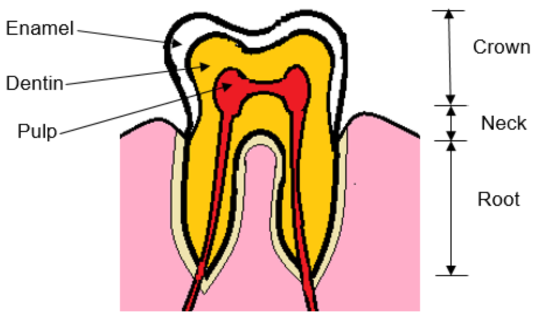

Figure 1. Tooth anatomy

From the tribological point of view, the enamel is the main element [2]. Its principal function is in protecting the teeth, while dentin is liable for cushioning the loads acting over the teeth.

The specialised literature provides enough information about the four terms used within dental tribology, which are attrition: wear due to tooth contact against the tooth, abrasion: wear of three bodies due to particles trapped in the zone of occlusion, erosion: wear due to the chemical attack of fluid without a bacterial origin, and abfraction: wear occurred at high biomechanical loads [2,6-8].

Nowadays, dental restoration materials can be classified into three groups: metals and their alloys, polymers and compounds, and ceramics [2]. During the last three centuries, metals have been the most used materials for dental restoration, being the amalgam employed successfully for approximately 100 years [9]. However, metals present some problems from the dental point of view, since they can present incompatibility with the dental tissue and their colouration differs from the teeth. In addition, mercury contained in the amalgam can cause other diseases [10].

The polymers and compounds, introduced in the mid-60s of the previous century [11], are currently the most used material and are one of the best alternatives to the use of amalgam [12,13]. From the dental point of view, they present good aesthetics because their colour resembles dental tissue and has good bonds with it [2]. However, from the tribological point of view, they have a higher wear rate compared to metals, which reduces their useful life [14,15].

Finally, ceramics, currently the material with the great potential because they have excellent dental and tribological characteristics, was successfully used in dentistry in 1774 [16,17], but these have some problems, due to their properties; they can show fractures and generate considerable wear on the antagonist [18,19].

2. Material and preparation

At present, on the market, there is a wide variety of materials for dental restoration that frequently are used in clinical and scientific laboratories. The materials chosen for the trials are presented in Table 1.

The used metallic material was dental silver in a rectangular shape of approximately 11 × 9 mm and a thickness of 1 mm is encapsulated inside crystal resin to be polished and mounted on the tribometer. Composite materials are obtained from 10 × 10 mm square glass resin moulds, and a depth of 2 mm, which were filled with Filtek Z350 XT composite, subsequently compacted and applied photopolymerization, according to the parameters of the manufacturer's recommendation. Lastly, the ceramic specimens are made using circular moulds of 1 cm in diameter and a 3 mm thickness, and the parameters for their making are according to the manufacturer's specification. Similarly, ceramic samples are covered with crystal resin, in order to be placed on the tribometer for its wear evaluation resistance.

Table 1. Dental restorative materials

Material and trademark	Element, wt. %	Hardness (HV)	Roughness (*Ra*), µm
Ceramic: Ceramco 3	O: 42.26 Na: 2.82 Al: 8.22 Si: 33.50 Cl: 0.27 K: 10.65 Cr: 0.95 Mn: 1.34	516 ± 9	0.18 ± 0.02
Metal: dental silver	O: 2.94 Si: 0.54 Cu: 9.57 Ag: 86.95	139 ± 6	0.16 ± 0.02
Composite: Filtek Z350 XT	O: 44.54 Na: 0.45 Si: 32.45 K: 1.09 Zr: 21.46	79 ± 5	0.16 ± 0.01

All the samples made with the different dental restorative materials were fabricated as flat samples; subsequently, the samples were polished until to reach the average roughness values and the measured hardness, both shown in Table 1. These were obtained using a Galaxy GR 260 roughness tester and a hardness tester Leco LM 700, respectively. The employed counter-body was a pin of Ni-Cr dental alloy of the semi-spherical shape of 5 mm in radius [20,21], since it has approximately intermediate hardness to that of the dental enamel, i.e. HV 360 ± 17 and for being a material with high corrosion resistance due to its chemical composition (53.60Ni-19.50Mn-14.50Cr-9.50Cu-1.60Al-1.60Fe).

3. Experimental methodology

To simulate attrition, the tests were carried out on a reciprocating machine. In this way it is possible to resemble this phenomenon as it occurs inside the oral cavity, isolating only this wear mechanism and carrying it out in a lubricated condition (artificial saliva) and dry condition, representing a case of shortage of saliva (Xerostomia), taking into account that these materials were used as dental restorers in the area of dental occlusion. Experimental tests were carried out by a reciprocating tribometer, manufactured at the IPN by the ESIME Zacatenco Tribology group, as shown in Figure 2.

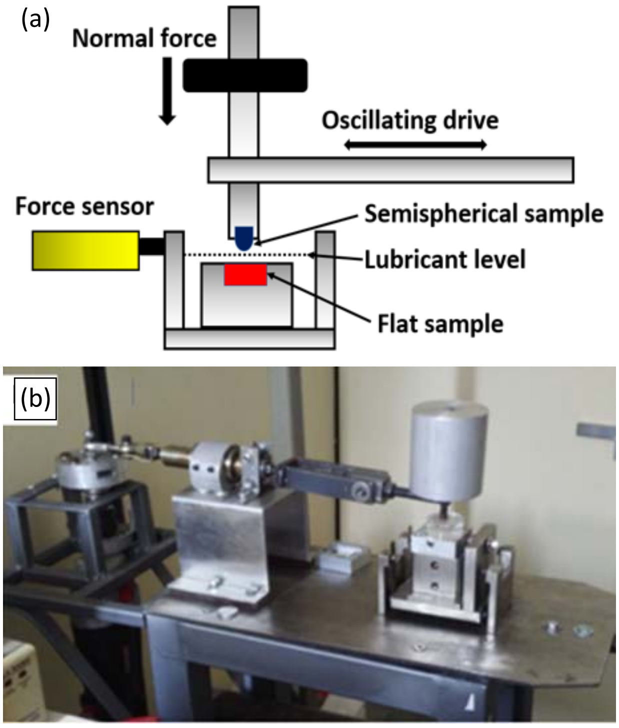

Figure 2. Tribometer: (a) tribometer diagram and (b) manufactured reciprocating tribometer

The used experimental parameters were determined by preliminary tests and based on some publications in which dental restorative materials and tooth enamel have been studied [3,20-22]. Table 2. shows the parameters used for dry and lubricated conditions, mentioning that three repetitions were carried out for each pair of materials.

Table 2. Experimental parameters

Parameter	Value
Normal load	10 N
Trace length	3 mm
Frequency	3 Hz
Cycles	2700

4. Results

4.1 Behaviour of the friction coefficient

Figure 3 shows the graphs of the friction coefficients of the materials used during the tests. They exhibit the differences according to cycles at dry and lubrication conditions.

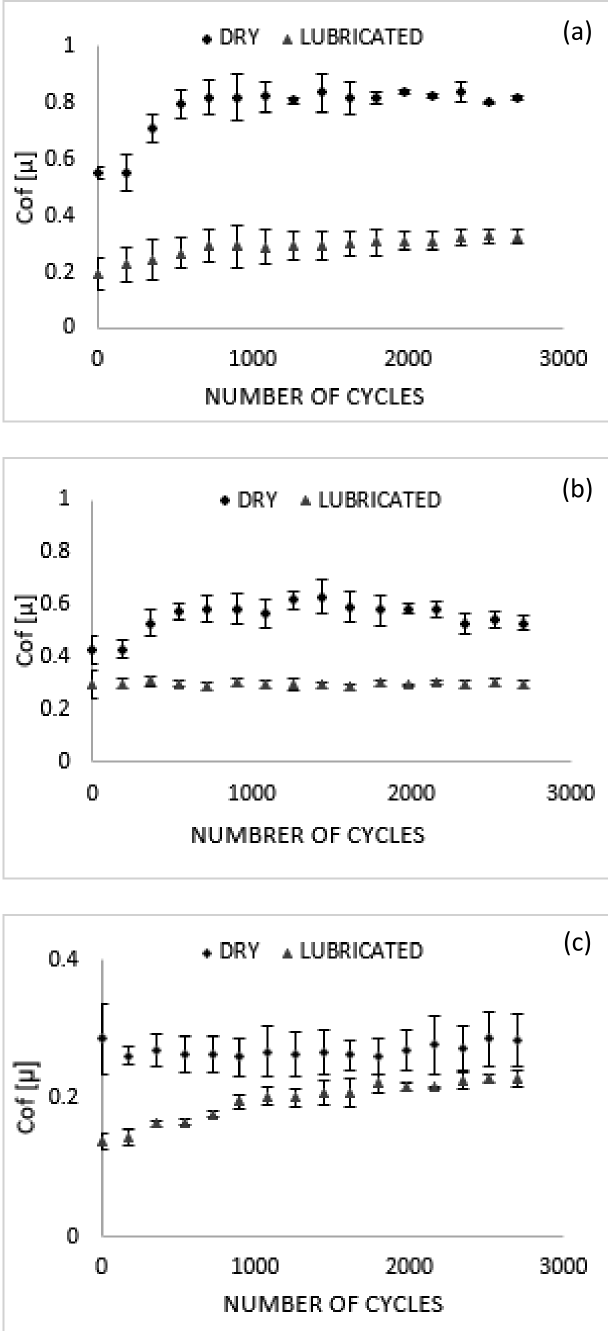

Figure 3. Behaviour of friction coefficients in dry and lubricated conditions: (a) ceramic, (b) metal and (c) composite

Graphs show that there is a significant difference between friction coefficients (CoF) in dry and lubricated conditions. In dry conditions, ceramic material (Fig. 3a), as well as the metal material (Fig. 3b), present the highest values with a tendency to increase until showing slight stability. Similarly, composite material (Fig. 3c), displays lower values.

Regarding the lubricated condition of all materials, it is observed that values are reduced for the friction coefficient. It is also remarkable that there is not found significant variability between them. CoF values on ceramic and metal materials (Figs. 3a and 3b) tend to decrease. A composite material in lubricated condition exhibits a slight reduction of the CoF values compared to dry condition.

4.2 Wear mechanisms and wear volume

The micrographs were obtained by SEM under dry and lubricated conditions. Based on Figure 4, it is found a significant difference in the worn surfaces of tested materials.

Materials tested in dry conditions show severe damage in the wear scars (Fig. 4). The main wear mechanisms such as fractures and cracks produce material delamination. However, results describe that the ceramic wear scar was the biggest. Secondly, it is found metal wear scar and finally the wear scar in the composite.

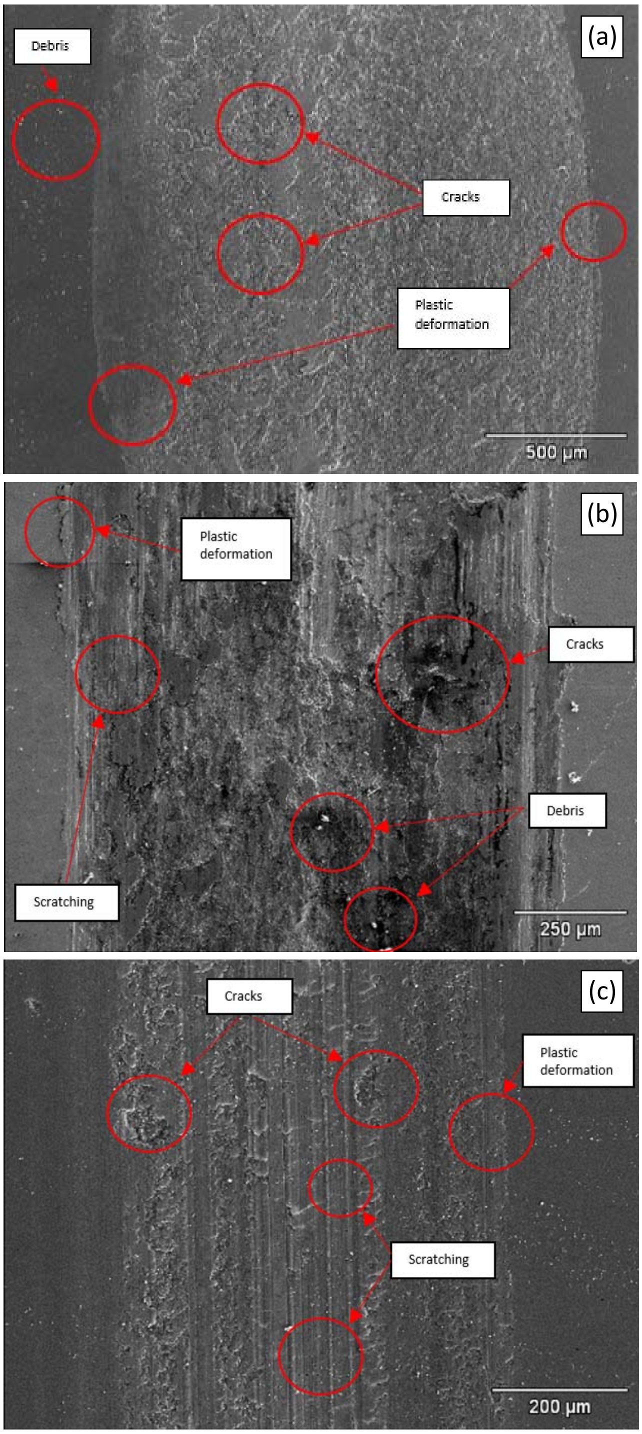

Figure 4. Wear scar micrographs of the materials: (a) ceramic, (b) metal and (c) composite, dry conditions

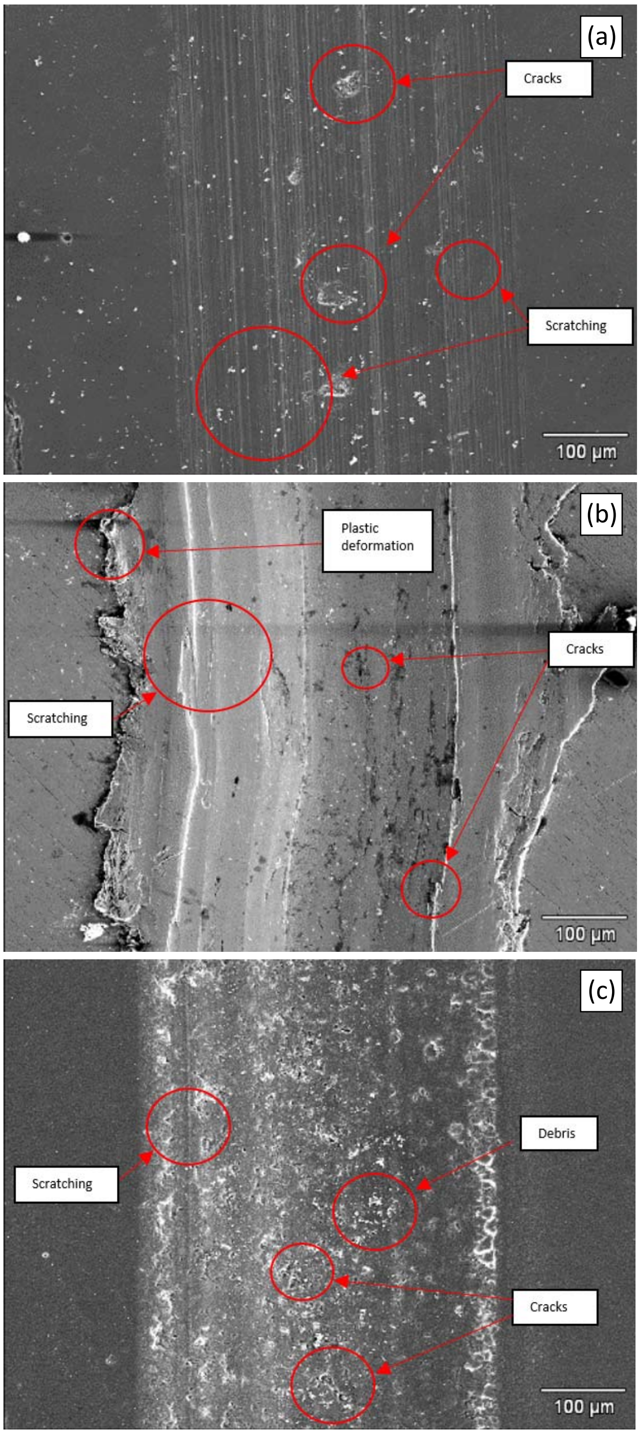

Figure 5. Wear scar micrographs of the materials: (a) ceramic, (b) metal and (c) composite, lubricated conditions

Materials tested in lubricated conditions (Fig. 5) show that the worn surfaces suffer from less damage but they displayed similar wear mechanisms to dry conditions. Opposite to dry conditions, there is no significative delamination, although the metal material presented a more severe plastic deformation.

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Figure 6 displays the wear volume loss of dental restoration materials used in this experiment. The left column shows the wear in dry conditions. The right column presents the wear in lubricated conditions. The results show that the ceramic and dental silver samples in dry conditions develop more severe wear than in lubricated conditions. Finally, composites materials exhibit an opposed behaviour, in the dry conditions the wear is less severe than in lubricated conditions.

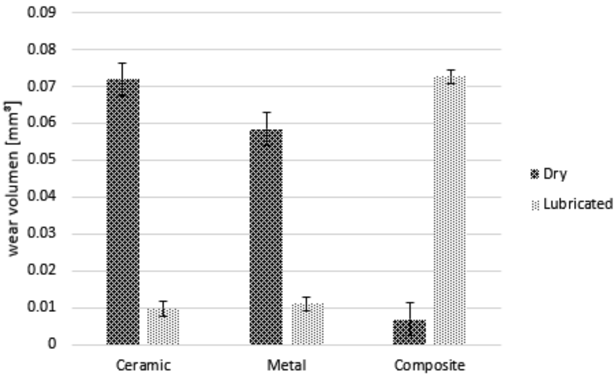

Figure 6. Wear volume

The wear scars were measured with a Mitutoyo CV 500 profiler. This equipment has a resolution of 0.0002 mm on the *z*-axis and a full linear stroke of ± 25 mm. Figure 7 displays the profiles in dry and lubricated conditions. Materials of ceramic and metal in dry conditions develop deeper wear scars in comparison with the lubricated conditions. However, a composite material in lubricated conditions presents deeper wear scars than in dry conditions.

5. Discussion

Because the oral cavity is a very complex biotribological system, only sliding wear (attrition) was considered given that in the real context, dental wear is presented as a combination of the wear mechanisms mentioned in the introduction.

The dry state of the tests can be considered a non-existent state due to in the oral cavity there is always the presence of saliva. However, it is presented in the clinical manifestation called Xerostomia.

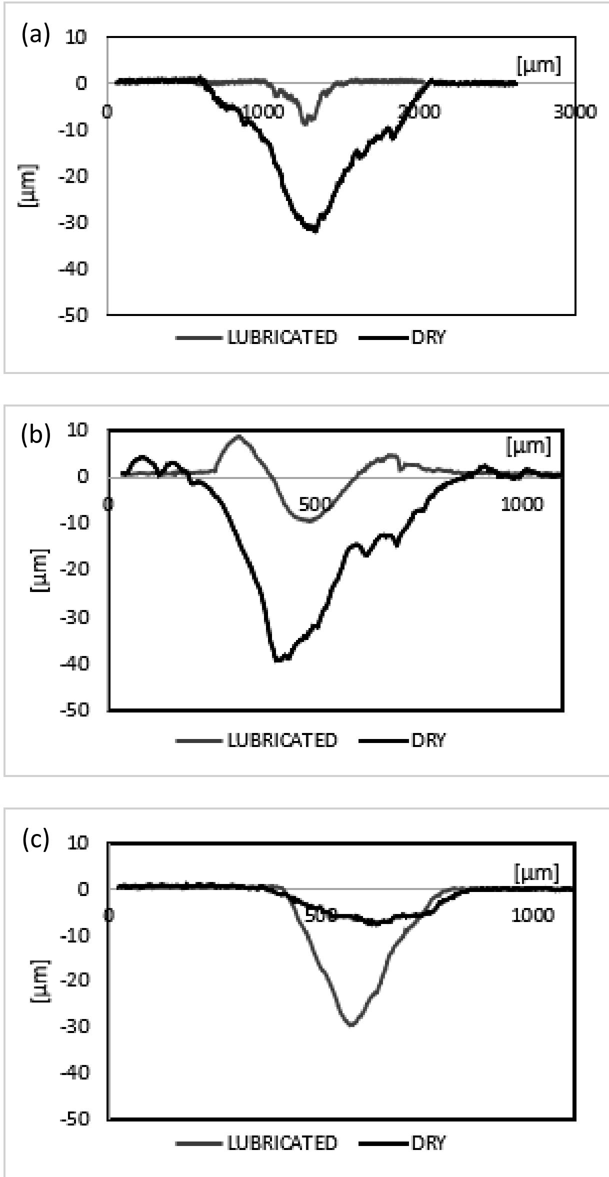

Figure 7. Profiles of wear scars in dry and lubricated conditions: (a) ceramic, (b) metal and (c) composite

As expected, the friction coefficients for each pair of materials (Ni-Cr alloy vs. dental restoration material), were much higher in dry conditions as shown in the graphs in Figure 3. It is observed that in dry conditions, the materials: ceramic and metal, showed an initial value of approximately 0.55 and 0.4 respectively, it will increase after the running-in phenomenon until reaching values of, around 0.8, for ceramic (Fig. 3a), followed by metal (Fig. 3b), showing a value close to 0.6, and finally, the composite (Fig. 3c), oscillating around 0.28, the latter showing greater stability throughout the test. However, the latter did not show the same behaviour as the other materials since, after the running-in, the value of the friction coefficient showed a decreased behaviour starting with values of 0.28 and decreasing to 0.26 until approximately 2000 cycles. Passing this point the coefficient increased slightly.

In addition, Figure 3 shows the results of CoF obtained in the lubricated conditions that as expected showed a reduction. For the ceramic material, it showed an initial value of 0.2 until reaching values of approximately 0.3 showing the greatest reduction of the materials tested; the metallic material showed a reduction to 0.3 showing stability around this value; finally, the composite material showed a slight reduction compared to its dry conditions, showing an initial value of 0.18 until reaching values of 0.2.

Although the values shown cannot be directly compared with those obtained by other authors because the tested pairs are different, these show the same trends in the behaviour of friction coefficients in dental enamel and dentin, as well as in materials of dental restoration [20,22-24]

On the other hand, in the morphology of the wear marks it can be found that for the ceramic material in dry conditions, the typical behaviour of ceramic materials is presented. These tend to fracture [25,26] due to the fatigue caused by the tests, which is reflected in the appearance of cracks and subsequent detachment of the material, as shown in Figure 4a. This same phenomenon is observed in lubricated conditions only on a smaller scale, as shown in Figure 5a, where it is observed that the saliva helped to reduce wear significantly, as shown in Figure 6. The volume lost in lubricated conditions was much lower; in the same way, Figure 7a shows the depths of the wear scars which in the dry conditions are wider and deeper.

For the metallic material, fractures and plastic deformation presented the main wear mechanism in dry conditions. They caused delamination of the material as shown in Figure 4b. The same happened in lubricated conditions, however, the plastic deformation was greater as shown in Figure 5b, which can be verified in the profilometry (Fig. 7b) where it is observed that the plastically deformed material was concentrated around the wear scar. This material also presented a considerable wear volume decrease in lubricated conditions compared to its dry conditions, as seen in Figure 6.

Finally, the composite material presented behaviour opposite to the other materials since in lubricated conditions the wear was greater than in dry conditions, as shown in Figure 6. Despite the fact that in the micrographs the damage presented in dry conditions appears to be much greater due to the presence of fractures and areas with material detachment, this damage only occurred on the surface of the material, as shown by its profilometry (Fig. 7c). Here it can be also observed that the depth of the wear scar in the lubricated conditions is greater, however, the micrograph does not appear to show significant damage, only showing fractures and the presence of debris. This phenomenon is due to the fact that in the composite material it presented a chemical reaction known as corrosion, which in dental composite materials causes a swelling in the material, due to the separation of the polymeric chains due to the absorption of a solvent [27], which makes the material softer. Due to the corrosion suffered by the composite material, the attrition-corrosion phenomenon was generated, which caused greater wear in the lubricated condition.

6. Conclusions

Ceramic and metal materials were tested to display severe wear during the development of dry tests. However, in lubricated conditions, these materials show less wear. This is a better choice against the phenomenon of attrition as long as saliva serves as an adequate lubricant.

The principal wear mechanism was fatigue because this causes cracks on specimens that subsequently release material.

Employing of counter-body made of Ni-Cr alloy, used reciprocating tester was right because displays similar behaviour on friction coefficients as well as wear mechanisms are simillar to the other authors.

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