Researches on Abrasive Wear Behaviour of Restorative Composite Materials for Dental Structures

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The most modern restorative interventions in dental practice are mainly based on a new generation of composite materials specialy designed for this kind of applications. Their complex structures offer a quasi-plastic behavior concerning the special tribological phenomenon developed in the intraoral environment. Starting from this, the paper intends to present the experimental data obtained as research results for two composite materials - InLine (IVOCLAR) and HeraCeram (HERAEUS Kulzer). The study is focused on the influence of the most important mechanical factors from occlusion areas such as loads, lubricants, speeds, composite materials hardness concerning the wear processses and their influence onto the mastication areas.

Keywords: composite materials, tribology, wear, dental medicine

Although a great number of processes may affect the integrity of dental structure and restorative materials, an increased interest raises the wear process. Wear is a normal phenomenon seen at the dental level and restorative material too, at the intraoral environment, in the presence of lubrication, so in wet conditions; for an occlusion contact area about 1-4 mm^2 and a cycles number of mastications about 800-1400/day could be supported loads up to 60-250 N, but which for short periods of time can even get to 500 - 800 N, and in case of para-functions as bruxism type acquire even values of 1000 N.

In the more extensive area of restorative therapy, the usual materials are frequently replaced by new types, the selection criteria are influenced by the wear resistance, compatibility with oral neighboring tissues, neutrality in oral fluids, and of course, aesthetics aspects. However the wear process itself of the material mass is influenced by specific factors such as: the type of load, the lubricant used and its speed, the quantity of included material, hardness etc.

Knowledge of the main mechanical properties that characterize restorative materials has become an essential requirement for their successful implementation in the field of restorative therapy. Thus, the behaviour under the loading tensions, the materials ability to be transferred, associated with the occurrence of the response strains, are very important properties that may influence their use as structural element in contact with the load occlusion.

To this is associated the natural resistance to abrasion of new occurred materials; the behaviour of quasi-plastic composites from the latest generation requires quantification of this very important feature.

For practice there are important those parameters that can be evaluated clinically and can be measured both *in vivo* and *in vitro*, using samples and comparable methods.

In this way, it is important to determine the volume of spent material; in this case the wear is defined as a permutation of a material mass, the mastication parameters (occlusion forces, number of mastication cycles, sliding distance) remained constant over time.

Experimental part

To determine the wear coefficient and the volume of spent material were tested two types of composite materials used in restorative dentistry practice: *InLine* (IVOCLAR) and *HeraCeram* (HERAEUS Kulzer) from which there were made samples in the form of discs with a radius of 25 mm and a thickness of 2 mm (0.5 mm metallic support and 1.5 mm phiz composite component) (fig. 1).

Casting, processing and finishing disks were performed sequentially, according to instructions and instruments of production companies.

The experiment was realized using a CALOWER-CS tribometer [1], a tool that allows both the thickness of deposited layers, and their coefficient of intrinsic wear (fig. 2).

A sphere of known diameter is applied on a particular task with a sliding motion on the studied surface; both the relative position of the sphere and the pressure load are constant. Sliding velocity between sphere and the sample is constant during the test.

Tests were performed with sphere speeds between 75 min^{-1} and 376 min^{-1}, achieving friction length between 16277 mm and 3255 mm, corresponding to approximately 35.000 mastication cycles on a contact occlusal length of 0.5 mm.

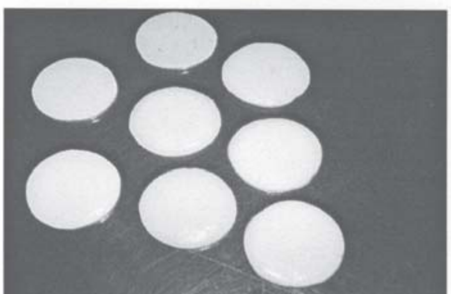

Fig. 1. Samples of restorative composite material a) a general view

The relationship between the volume of spent material and time is tested in an artificial environment; mastication parameters (occlusion force, number of mastication cycles, sliding distance) are controlled and constant over time; the lubricant used in testing is artificial saliva [2] whose composition is shown in table 1, and before applying lubricant, the testing samples surfaces should be cleaned with alcohol.

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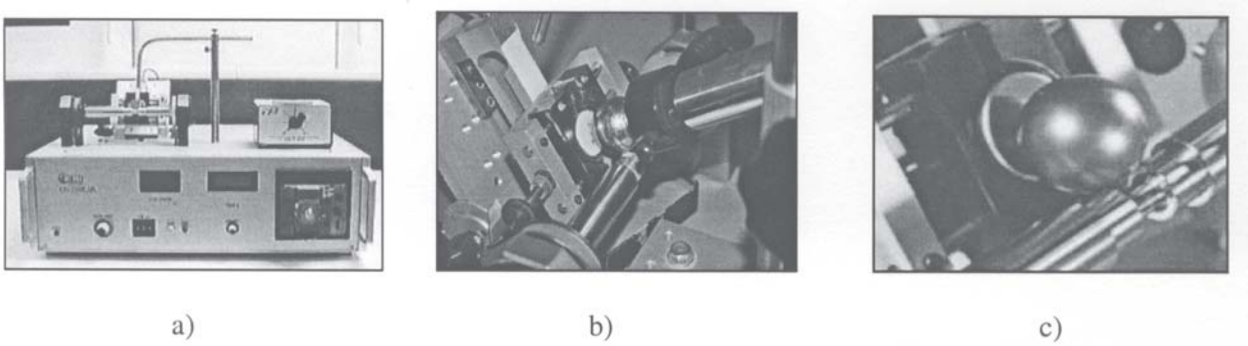

Fig. 2. CALOWER tribometer. a) general view, b) testing head ensemble, c) testing head detail

Table 1
ARTIFICIAL SALIVA COMPOSITION

NaCL	KCl	$CaCl_2$x $2H_2O$	NaH_2PO_4x $2H_2O$	Na_2S x $9H_2O$	Urea	Distilled water (ml)
0,4	0,4	0,795	0,78	0,005	1	1000

Each wear test was repeated at least 3 times; there were calculated the average value and mean square deviation for the volume of spent material.

The volume of spent material was determined based on the diameter of wear stain; the measurement of its diameter was realized with the help of an optical microscope.

Variation of tangential force according to the displacement was recorded automatically inside the operation cycles, and waste areas were then examined by various methods of optical microscopy.

To determine the main parameters of the contact between sphere and flat surface of the tubes for the beginning moment of the wear test (maximum contact pressure, average pressure contact and radius of contact spots) there were applied Hertz contact theory details.

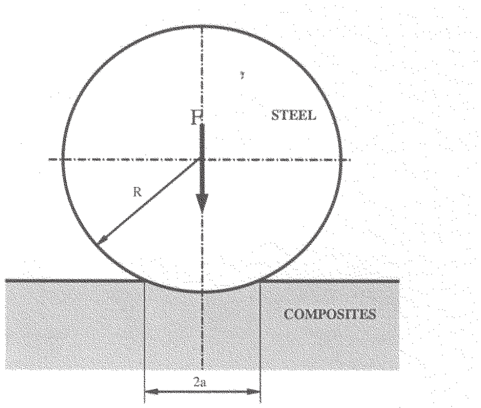

Fig. 3. Contact area composites - steel sphere

Results and discussions

Applying the specific calculus for contact theory able to determine the wear of composite material beeing in contact with the metal sphere, there were obtained the values for the material parameters, geometry and loading (fig. 3), (table 2). It was determined the abrasive wear coefficient for the two composite materials taken in the study.

Based on all tests performed, there are observed no significant differences between the coefficients of abrasive wear for the two types of composites produced by IVOCLAR - *InLine*: 0.011296079 mm3/Nm and HERAEUS Kulzer - *HeraCeram*: 0.01085531 mm3/Nm) (table 3, table 4, fig. 4, fig. 5).

For *InLine* composites the volume of spent material increases in proportion to the contact depth (a factor of approximately 0.003 mm^3/Nm for an average depth of 0.97 mm).

Unlike *InLine* material, *HeraCeram* composites becomes more resistant to abrasive wear and the amount of material deformed and displaced decreases proportionally with increased capacity of composite material to withstand the force exerted on it.

Tabel 2
TESTING PARAMETERS

Material properties				Equivalent elasticity module [MPa]	Contact radius [mm]	Task load [N]	Maximum pressure [MPa]	Medium pressure [MPa]	Contact stain radius [mm]
Steel ball		Sample of restorative composite material							
Elasticity module [MPa]	Poisson coefficient	Elasticity module [MPa]	Poisson coefficient						
210000	0.3	358000	0,3	145450	12,7	0,35	207	138	0,028

Tabel 3
VOLUME OF SPENT MATERIAL AND THE COEFFICIENT OF ABRASIVE WEAR FOR *InLine* COMPOSITES

Shaft rotation [min^{-1}]	Crater diameter [mm]							Length of friction [mm]	Spent volume [mm^3]	Deviation	Wear coefficient k [mm^3/Nm]
	D1	D2	D3	D4	D5	Average	Deviation				
75	1	1	0,9	1	0,95	0,97	0,044721	3255	0,003422	1,54606E-08	0,003003165
150	1,5	1,4	1,3	1,4	1,4	1,4	0,070711	6511	0,014848	9,66287E-08	0,0065159
225	1,6	1,8	1,7	1,8	1,7	1,72	0,083666	9766	0,033828	1,89392E-07	0,009896572
300	1,8	2	1,9	2	1,9	1,92	0,083666	13022	0,052526	1,89392E-07	0,0115249
375	2	2,05	2	2,05	2	2,02	0,027386	16277	0,064353	2,17415E-09	***0,011296079***

Crater diameter [mm]							Length of friction [mm]	Spent volume [mm^3]	Deviation	Wear coefficient k [mm^3/Nm]
D1	D2	D3	D4	D5	Average	Deviation				
0,8	1,1	1,4	1,4	1,2	1,18	0,248998	3255	0,007494	1,48576E-05	0,006576885
1,1	1,5	1,8	1,5	1,4	1,46	0,250998	6511	0,017562	1,53408E-05	0,007706793
1,5	1,7	1,9	1,7	1,6	1,68	0,148324	9766	0,03079	1,87073E-06	0,00900758
1,6	1,9	2,1	1,8	1,8	1,84	0,181659	13022	0,044303	4,20915E-06	0,009720835
1,9	2,1	2,2	1,9	1,9	2	0,141421	16277	0,061842	1,54606E-06	***0,01085531***

Table 4
VOLUME OF SPENT MATERIAL AND THE COEFFICIENT OF ABRASIVE WEAR FOR *HeraCeram* COMPOSITES

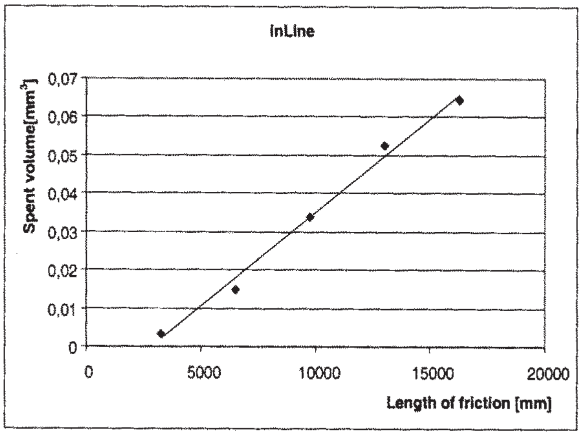

Fig. 4. Average volume of spent material depending on the length of friction for *InLine* composites

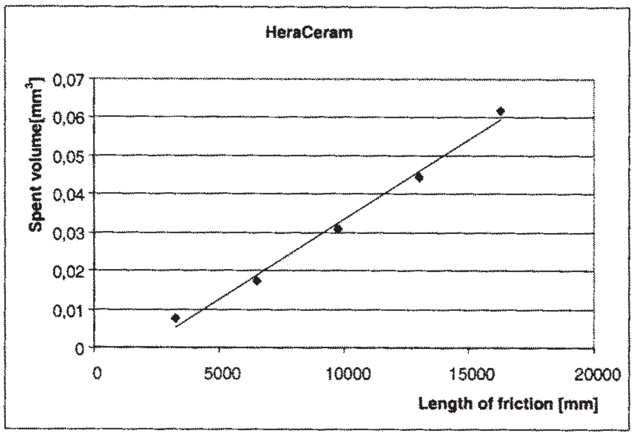

Fig. 5. Average volume of spent material depending on the length of friction for *HeraCeram* composites

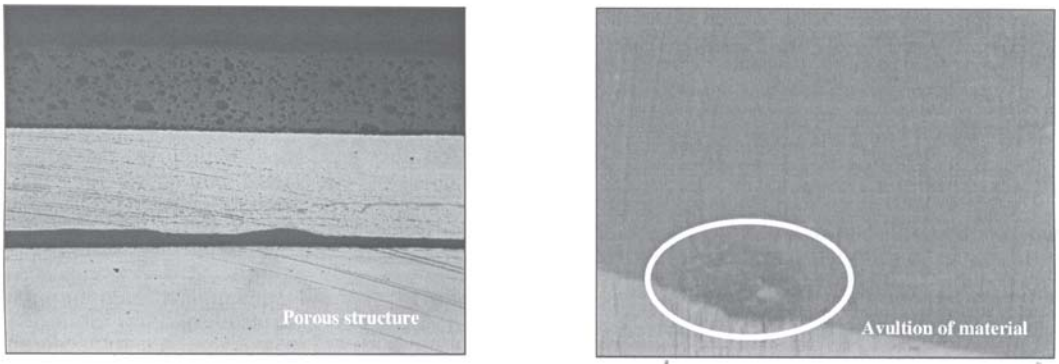

Fig. 6. Microscopic aspects of *InLine* composites

It is observed a linear relationship between the volume of spent material and the length of friction.

The volume of spent material increases in proportion to the number of rotations and the length of friction; if the length of friction of 3255 mm corresponds to an abrasive wear coefficient of approximately 0.003003165 mm^3/Nm for *InLine* composites, it is found that for the same length, the coefficient of wear for the *HeraCeram* is 0.006576885 mm^3/Nm.

It should be noted a progressive increase of the diameter of wear spots with a corresponding increase in the volume of spent material.

It is noted that the *InLine* material reveals a much better resistance to wear by abrasion, abrasive wear coefficient decreasing proportion with resistance increasing.

Seen under the optical microscope, the area of wear is clearly different compared to the two materials (fig. 6, 7).

For *InLine* composites there are observed cracks and changes in the composite mass, a sign that it was a waste of material at this level. The surface appears to be roughness and more porous compared with the area which was not tested. In figure 6 there is a visible area of material avulsion accompanied by the presence of cracks.

These microscopic aspects characterize each wear surface separately.

Microscopic appearance of the *HeraCeram* composites shows changes in mass of spent composite material (fig. 7). Hard metal support which strengthens the composite facilitate its separation in the contact area. There are associated flakings with uprooting and displacement of material, which combination is highlighted. It is visible too a free space between the metallic support and the composite material as a sign of phiz material detachment from the underlying metal skeleton.

Comparing the coefficients of abrasive wear of the two composite materials studied it is observed that for the same length of friction, the volume of spent material increases in proportion to the wear coefficient, the material with the best resistance to abrasion wear beeing *HeraCeram* composites; *InLine* material is very easy abrasived.

The graphical representation highlights the difference between the wear coefficients for the two composite materials studied (fig. 8, 9).

This coefficient variation of wear abrasion could be made in close connection with some structural aspects which will be discussed later, when assessing the quality of used surfaces.

Reporting the volume of spent material obtained for the same length of friction, there is a linear increase in the quantity of material moved with increasing distance of the metal sphere sliding (fig. 9).

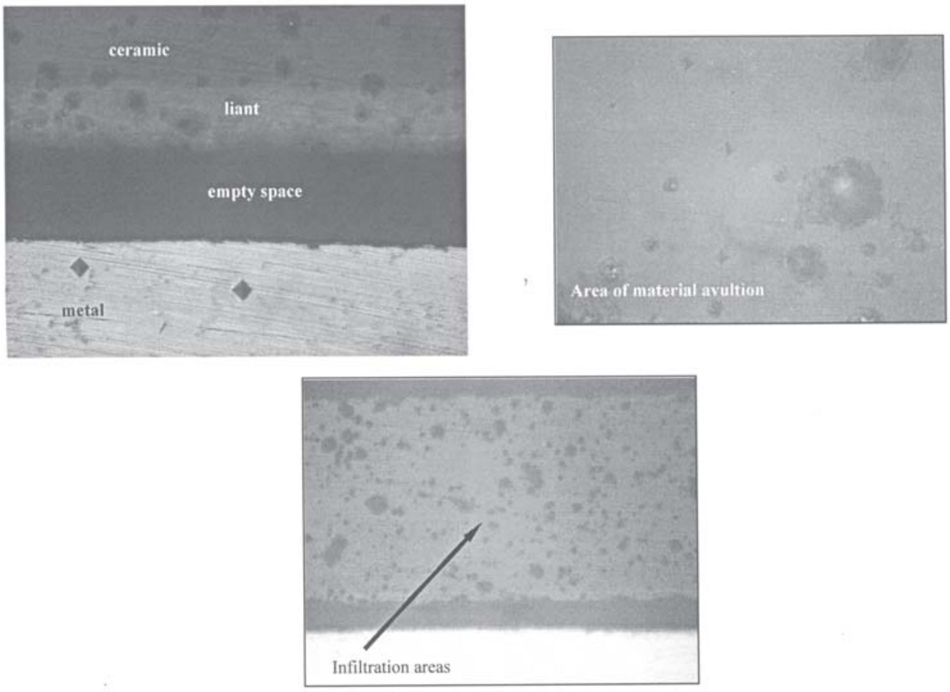

Fig. 7. Microscopic aspects of *HeraCeram* composites

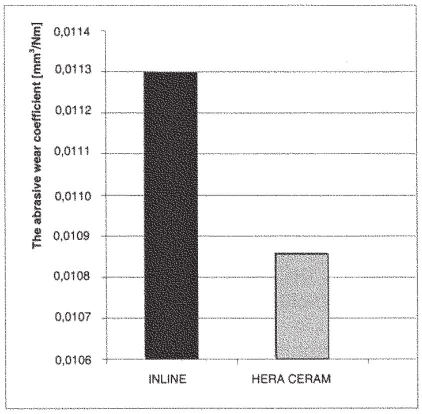

Fig. 8. Variation of abrasive wear coefficient [mm^3/Nm] for composite materials

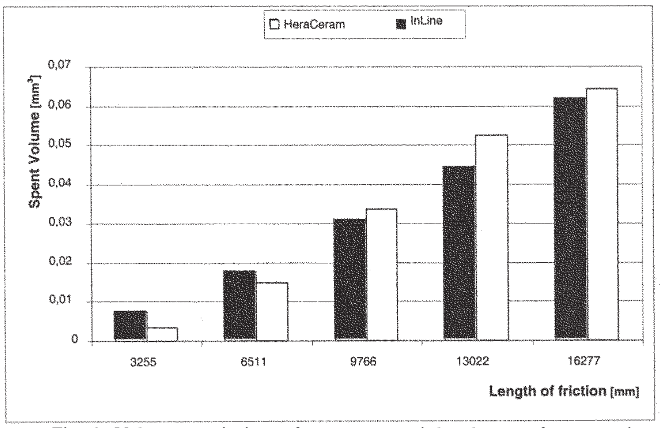

Fig. 9. Volume variation of spent material volume of composite materials depending on the length of friction

Thus, if in the early stages of testing *HeraCeram* emphasize an increased value of the material spent volume, and *InLine* the lowest percentage of material loss, as the length of friction increases will apppear changes in mass of material lost by abrasion, reach that a length of friction of a high enough value (16.277 mm) the lowest volume of spent material to be available for *HeraCeram* composites (0.061 mm^3), compared with *InLine* whose value is about 0.064 mm^3.

It is thus confirmed that the wear factors are dependent on the load for all areas taken in the study, justifying their use in trying to normalize the measurable parameters of wear.

The results of this study suggest that there is an inversely proportional relationship between the hardness and the abrasion wear behavior of solid materials, in our case restorative composite materials, as is mentioned in Borgiolli's studies [3].

The *InLine* material with a higher hardness shows narrow and not deep wear traces; on the other side the hardness of *HeraCeram* material causes heavy losses of material during testing. It is possible that in the absence of lubricant, the displaced composite particles themselves become part of the wear process and contribute to a widening of already installed process [4-6].

The *HeraCeram* material, while presenting a very high hardness, however the aluminum content makes the material breakable, giving it a certain fragility, as well as notes in the tables with values presented above.

Resistance values obtained indicate that the size (depth) of the actual spots of wear influenced the test results in the case of crystalline materials; this phenomenon is explained by so-called concept of " necessary geometric displacement": for the same samples diameter, the different diameter of produced traces affect the plastic response of the material, notably the fact that composites are strongly anisotropic materials [7].

In affected areas by the deformation process there are occurring outstanding "clogs" from recrystallization process. In addition, individual crystals are themselves markers of the spent surfaces; this fact is underlined by the microscopic aspects specific for spent areas. The properties of deformed layers affect the mechanical properties of the material, which at their turn are influenced by the amount and depth of deformation of the surface layers.

The type and size of the testing sphere gave a specific character for all experimental determinations; its diameter is increasing in proportion with the depth of penetration in the same time with the contact stress increasing; therefore, the response of transition from elastic to plastic and the properties determination of contact stress represent special characteristics of composite materials.The stress in the contact area increases proportionally with depth print and inversely with the volume of spent material, which is well shown by the values obtained in the study for the two types of restorative composite materials.

For composite materials with an increased fragility (in our case *HeraCeram*, very breakable material), spherical contact will develope or conventional conical cracks on the studied surface of studied, or radial cracks which are easier appearing in finest layers in the flexure field. Initiation of cracks occurs in depth, followed by their propagation to the surface layers or lateral areas. Lateral cracks develop and multiply with load increasing until, by the penetration of the surface; they occurs interface delamination accompanied by a loss of structure [8, 9].

However, finally the material mass fracture occurs due to stress concentration at a surface defect. In fact, the stress applied to the surface, especially when at this level there is a defect is equal to the intrinsic resistance of the material. Once initiated, fracture extends, especially by increasing the factor of stress concentration. The presence of defects in composite material mass is the main factor affecting the wear resistance of this type of material, other factors such as the chemical composition of the matrix can have a direct impact on resistance, but with a low interest.

The coefficient of thermal expansion of composite masses must be equal to the alloy on which are burned, because during the combustion process appears a modification of the two coefficients of thermal expansion (for alloy and for composite material). This fact will have as a result the occurrence of the phenomenon of wear fatigue, with detachment of material from underlying support (as evident in the case of *HeraCeram* material).

It is well known that it is difficult to replicate in "*in vitro*" conditions the mastication movements of the oral environment. Although the movements made by tribometer could not reproduce the mastication cycles in their entirety, it was possible to simulate a simple motion, which included the phases of gathering and mastication. Sliding motion associated with the length of sliding (friction) plays, in its turn, a particularly important role in simulation of intra-oral wear. Thus, the occurrence of cracks in the mass of composite material is made approximately 10 times faster if the load was applied with sliding elements, compared with static compression between surfaces.

At oral level, where there is an alternation between compression areas and tensile areas, materials being in direct contact practically slide over one another, and the resulting plastic deformation causes the appearance of areas of tension during the movement associated with nuclear substrates cracks, cracks which propagated in repetitive cycles. These materials sliding leads to so-called "debrisses" of wear which can produce in their turn the abrasive process. External and internal layers morphology is different, causing changes micro-hardness and an implicit differential wear. The asperities of wear composite surface will preferentially abrasive the surface of antagonist arcade. Occurrence of fine particles on the contact leads to exfoliatings at its own level accompanied by scratchings, and finally by affecting the both surfaces (as noted in the microscopic study). There are a multitude of occlusion contacts, contacts that can be influenced by the presence or absence of food bowl (the wear for two, respectively three corpuses) and which can lead to so-called wear "mutual wear".

Metallo-composite reconstructions have a low resistance to traction and because of this cause the plywood composite will be away from such loads. The tensile strength of alloy-composite interface is approximately by 125-315 kg/cm^2 at different breaking tests carried fracture appearing in composite mass thickness and not to interface level. If the thickness skeletal metal is less than 0.3 mm may appear tensions which lead to a plywood composite fissure.

Occlusive contact area will always be the same on the opposite material (of the same kind or not), but less than or equal to the corresponding surface area used. This is because, practically a material slides over the antagonist one during mastication movements, with the main consequence concerning the wear of mellow surface.

Conclusions

The volume of lost material evolve linearly with time if the material and the test conditions remain constant. The depth of penetration is proportional with a major vertical loss which is dependent on the occlusion factors.

Because the initial roughness of composite area is not determined when is trying aesthetics restoration, the wear that occurs between opposed enamel and composite surface occurs through abrasive action of two corpuses (due to initial surface roughness of composite) or abrasive action between three corpuses produced by the presence of wear residues of hard composite.

Biological interactions which has a great influence onto the sustainability of restauratives „in vivo", the production of wear residues, the analysis of all materials [10-16], can be achieved only in close liaison with clinicians.

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Manuscript received: 2.07.2009