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Wear Behavior of Dental Restorative Materials

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Key Words: Wear, New generation dental restorative material, FEM analyzing

ABSTRACT

Gradual wear of opposing teeth is a normal phenomenon in human dentition. There is a need for quality dental restorative materials to repair or replace natural teeth to ensure a higher quality of life through dental health. One of the main physiological mechanism that exists in dental materials during normal muscle function is called abrasion. There are two types of that in teeth which are common; Two-body and three-body. If the teeth are contacted directly, it is referred to as two-body abrasion. However, when there is abrasive slurry-like food between the teeth, this abrasive is called to be three-body abrasive. Several types of materials are available in current dentistry for teeth restoration and replacement, and new materials are being promoted every year.

Dental specialists need to understand the wear mechanisms of these new types of dental restorative materials, alone or in combination with either enamel or other dental restorative material. The present study evaluates the abrasive resistance of three restorative materials groups: direct composites, indirect composites, and ceramics. To define the resistance of the wear, the authors then perform a micro-wear test on chosen materials.

The results show that the wear mechanism is abrasive due to its low hardness compared to zirconia ball. The wear path in the nanohybrid (Grandio®, 87s% w/w (71s% volume) inorganic nanohybrid filler, BisGMA, UDMA, TEGDMA) sample was smooth and without particles. In this study wear FEM analysis calculated for all models and the answers compared with experimental data.

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INTRODUCTION

Rebuilding materials are a sub-gathering of what are for the most part alluded to as biomaterials: non-living material intended to connect with natural living beings. This study examines the advantages and disadvantages of several widely used restorative dental biomaterials regarding wear.

As the administration surroundings are that the mouth, dental remedial materials, and teeth are exposed to very explicit administration conditions (Cavalletti de RossiG. R. et al., 2020). Tooth wear is a widely acknowledged clinical problem, which has become increasingly pervasive, especially among aging populations. During mastication, the teeth, together with any restorations, have to move in constant contact with one another. As a result, friction and wear tend to occur with the lubrication of saliva or food slurry (Hesse H. and Özcan M., 2021). In order to minimize causal factors and develop new dental materials, experts must recognize dental friction and wear behaviors and enhance clinical diagnosis and management of tooth wear, to include the replacement of missing tooth tissue with dental materials (Ungar P., 2004). As a result of its growing prevalence, the study of tribology as it relates to dental materials has gained increased attention from researchers.

Two distinct methods are commonly used to analyze the wear of dental restorative material:

clinical (in vivo) and laboratory (in vitro) (Bianchi E. et al., 2002). Clinical tests are performed by installing the restorative and studying the outcome over time. Although relatively successful, there are problems associated with these types of trial tests. For one, the time necessary to obtain results is quite extensive, requiring a minimum of 2 years (Bianchi E. et al., 2002). Additionally, complete control of the testing environment is unrealistic since patients engage in various eating and mastication habits, and saliva production and overall health vary from patient to patient. Finally, ethical questions tend to surface in regards to conducting tests on materials without full knowledge of their behavior when installed. In terms of advantages, in vitro testing allows complete control over the variable involved in the wear of the dental restorative materials.

The main classifications of wear that contribute to the destruction of dental tissues and restorative materials are Physiologic wear (vital life functions), Pathologic wear (disease and abnormal conditions), Prophylactic wear (preventive measures) and Finishing procedure wear (Powers J. M. and Bayne S. C. et al., 1992).

In each case, the actual wear process may vary as the substrates, opposing wear surfaces, involved lubrication systems, and abrasive particles will likely differ. Dental restoration materials currently fall into one of three categories (direct composites, indirect composites, or ceramics), and are defined as the three-dimensional compound defined by at least two discrete chemicals that separate a single interface (Willems G., 1992). Defining the abrasive resistance of dental restorative materials through experimental analysis is the aim of this article.

MATERIAL AND METHODS

Experimental

Traumatic and pathologic factors are one of the factors that cause patients to have multiple and very long-lasting lesions in the teeth. In order to reduce the problems caused by these wastes, in recent years, various materials have been developed that are mainly synthetic Dobrzański, L. A. et al., 2020). They can be used as a suitable replacement for damaged parts of the tooth (tooth enamel and tooth tissue). These materials are used for two major purposes in dental science. The first is the aesthetic goal and the second the therapeutic and restorative goal (Upadhyay D. et al., 2006). The selection of a dental application requires focus and in-depth knowledge of the discipline. The material selection is associated with various factors, namely corrosion behavior, cost, availability, biocompatibility, aesthetics, and mechanical properties, including strength and wear resistance. Dental materials are typically divided into three sections, including metals and their alloys, polymers, and composites, and ceramics (Randall R. C. and Wilson N. H. F., 1999). Two main issues in dentistry are limited the former clinical usage: (1) the distinct difference in color from that of tooth tissue, and (2) the irritability or cytotoxicity of metal to cells.

The present study employed a reciprocating wear test with a plane-sphere geometry. Such a test permits variations in the amplitude of movement and contact conditions, specifically environmental solutions, as well as the ability to evaluate the wear of both materials in contact. For purposes of this study, tests were conducted with either artificial saliva or an abrasive solution to evaluate the effect of a third body on the wear of materials in contact. Both tests used glass zirconia balls with a radius of 6 mm as an antagonist, the values of which were selected to be similar to the curvature radius of molar teeth. In addition, five commercial dental restorative materials from the three groups mentioned above were used, each involving cube-shaped specimens with dimensions of 14 x 14 x 5 (Table 1).

Table 1- Properties of Tested Materials

Mechanical Properties	**Direct Composites**		**İndirect Composites**	**Ceramics**		**Tooth**
	Nanohybrid (Grandio)	**Mikrohybrid(FiltekZ 2)**	**Belle Glass**	**Feldspatics**	**Rezin Nano ceramic**	**Enemal**
Producer	Vacopostfach 767Guxhaven, Germany	Z2503MESPE,St-Paul, MN,EUA	BelleGlass,KerrLab Corporation west Collins Orange, CA, USA	Vintage Opaque 3M USA	Lava Ultimate, 3M bulding USA	--
Modulus of elastisity	20G pa	16 G pa	30 G pa	8 G pa	11 G pa	18Gpa
Poisson ratio	0.33	0.31	0.32	0.31	0.33	0.32
Surface	2.12 µm	2.53 µm	2.02 µm	1.89 µm	1.93 µm	1.81 µm

roughness (R_Z)						
Hardness (Brinell)	105mpa	109mpa	99,8mpa	287mpa	173mpa	300mpa
Modulus of plastisity	2Gpa	1,6Gpa	3Gpa	0,8Gpa	1,1 Gpa	1.8 Gpa
Yield strength	320	335	299,4	835	520	420

When materials had been taken, the consequent strategy comprised of a circle stayed in touch with the flat wear surface of the stationary item and engaged in reciprocating motion and sliding contact with a flat specimen of restorative material. During the chewing process in humans, the magnitude of the masticatory force in the oral cavity ranges from 30 to 120 N (gender and age (McGarry J. and Spangenberger A., 2012)), and the normal load in this study was fixed near the minimum referred values (Fig.1). According to the device standards a normal load of 50 N was applied to the ball, and the oscillatory movement was a set stroke length of 8 mm and a frequency of 2 Hz (Kaifu Y., 1996).

After testing, the specimens were scanned by a Roddenstock RM 600 laser stylus. Flat specimen scans were the transversal of the sliding direction, and the distance between profiles ranged from 20 to 30 µm, depending on the length of the wear scar. The zones of the 2-D profiles were coordinated along the length of the wear mark, enabling the creators to decide the volume evacuated by the wear of composite dental material (Lenart A. et al., 2020).

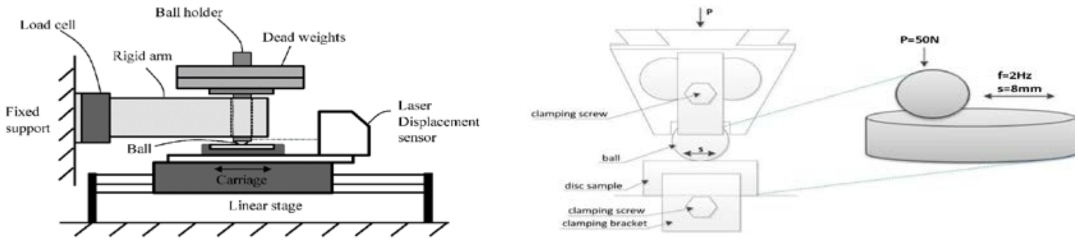


Fig.1. Illustration of the experimental fretting wear approach and Fretting Cycle (Kaifu Y.,1996)

Finite Element Analysis

Wear is the dynamic loss of material from outside of a strong body when in contact with another body. The program approximates this loss of material by repositioning the contact hubs at the reaching surface (Feilzer A. J. et al., 1987). The new hub areas are dictated by a wear model which computes how much and in what heading a contact hub is to be moved to recreate wear dependent on the contact results. This example shows the use of the Archard Wear model and also demonstrates the user-defined subroutine for modeling wear. Since wear involves material removal, the element quality of solid elements underlying the contact elements becomes progressively worse with increasing wear. Remeshing is required to simulate large amounts of wear successfully. This example demonstrates how manual rezoning or nonlinear mesh adaptivity can be used to improve mesh quality when a model undergoes large amounts of wear.

Reciprocating wear model was designed in AN-SYSY as Fig.2.

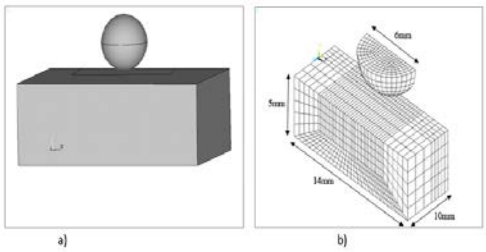


Fig.2. a) Full model and b) half model

The Archard wear model is specified by inputting constants C1 through C4 on the TBDATA command. These constants represent the wear coefficient (K), $C_1 = k = \frac{VH}{FS}$, material hardness (H), the contact pressure exponent (m), and the sliding velocity exponent (n) that is zero in this calculation.

Calculating C3 as contact pressure exponent:

Hertzian hypothesis depends on the reason that the reaching surfaces are in a perfect world smooth, and in this manner, flawless contact happens all through the ostensible contact zone. In any case, genuine surfaces have unpleasantness and contact happens just at discrete spots called smaller scale contacts where severities reach. The genuine contact region is typically a little portion of the ostensible contact territory (Thompson J. M., 2006) Hertz supplanted the reaching circles with paraboloids; subsequently, the contact between two circles was improved to the contact of a plane and a profile that has a compelling sweep of arch ρ, where 1/ ρ =1/ ρ 1+1/ ρ 2. "For expediency, all elastic deformations can be considered to happen in one body, which has an effective elastic modulus *E*, and the other body is assumed to be rigid; where,"

$$\frac{1}{E'} = \frac{1-{\vartheta_1}^2}{E_1} + \frac{1-{\vartheta_2}^2}{E_2} \qquad (1)$$

"Hertz proposed the following pressure distribution,

$$P_H\left(\frac{r}{a_H}\right) = P_{0.H}\sqrt{1-\left(\frac{r}{a_H}\right)^2} \qquad (2)$$

where $P_{0.H} = \frac{1.5F}{(\pi a_H{}^2)}$ and $a_H = \left(\frac{0.75F\rho}{E}E'\right)^{1/3}$

are the maximum pressure and the radius of the Hertzian contact area, respectively. "

If roughness is isotropic and randomly distributed, the surface is called Gaussian. Tentatively, Williamson et al. have indicated that a significant number of the procedures used to deliver designing surfaces give a Gaussian conveyance of surface statures. Many designing surfaces do not pursue symmetric Gaussian appropriation yet rather a lopsided circulation. In any case, in this examination, we center just around Gaussian surfaces Fig.3.

Table 2- Models Details

Models					
1.No	Lower Material	2.No	Upper Material	3.No	Load
1	Indirect Composite	1	Zirconia	1	25N
		2	Enemal		
2	Nanohybrids				
		3	Indirect Composite	2	50N
3	Micro hybrids	4	Nanohybrids		
		5	Micro hybrids		
4	Feldspatics	6	Feldspatics		

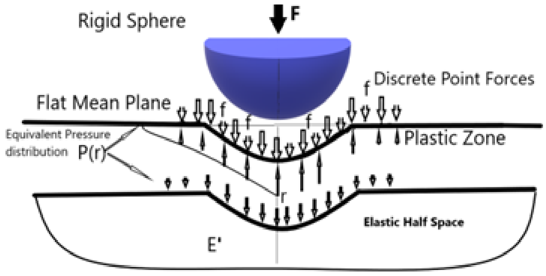


Fig.3. Contact between the sphere and rough plane

Pressure distribution profile begins to deviate from the Gaussian profile. So:

$$\gamma = 1.5\frac{P_0}{P_{0.H}}\left(\frac{a_L}{a_H}\right)^2 - 1$$

Where:

$$P'_0 = \frac{1}{1+1.22\alpha\beta^{-0.16}}$$

That:

$$\alpha = \frac{\sigma\rho}{a_H^2}\ , \qquad \beta = \frac{E'}{H_{mic}}\sqrt{\frac{\rho}{\sigma}}$$

And

$$a'_L = \begin{cases} 1.605/\sqrt{P'_0} & 0.01 \le P'_0 \le 0.47 \\ 3.51 - 2.51P'_0 & 0.47 \le P'_0 \le 1 \end{cases}$$

"After finding C1, C2, C3, and C4 values and putting them in TBDATA, from Archard equation, the wear value can be calculated."

In this study 115 models used for finite elements calculation, these models showed in Table 2 and wore values shoed in Table 3.

Table 3- Used Models Wear Values

Model	Wear	Model	Wear	Model	Wear	Model	Wear	Model	Wear
Model-1 .1. 1	0.012mm	Model-2 .1. 1	0.045mm	Model-3 .1. 1	0.070mm	Model-4 .1. 1	0.128mm	Model-5 .1. 1	0.132mm
Model-1 .1. 2	0.048mm	Model-2 .1. 2	0.095mm	Model-3 .1. 2	0.127mm	Model-4 .1. 2	0.219mm	Model-5 .1. 2	0.216mm
Model-1 .1. 3	0.100mm	Model-2 .1. 3	0.175mm	Model-3 .1. 3	0.244mm	Model-4 .1. 3	0.211mm	Model-5 .1. 3	0.322mm
Model-1 .2. 1	0.032mm	Model-2 .2. 1	0.066mm	Model-3 .2. 1	0.093mm	Model-4 .2. 1	0.110mm	Model-5 .2. 1	0.140mm
Model-1 .2. 2	0.073mm	Model-2 .2. 2	0.131mm	Model-3 .2. 2	0.179mm	Model-4 .2. 2	0.188mm	Model-5 .2. 2	0.229mm
Model-1 .2. 3	0.062mm	Model-2 .2. 3	0.197mm	Model-3 .2. 3	0.267mm	Model-4 .2. 3	0.276mm	Model-5 .2. 3	0.326mm
Model-1 .3. 1	0.033mm	Model-2 .3. 1	0.068mm	Model-3 .3. 1	0.097mm	Model-4 .3. 1	0.125mm	Model-5 .3. 1	0.149mm
Model-1 .3. 2	0.064mm	Model-2 .3. 2	0.122mm	Model-3 .3. 2	0.163mm	Model-4 .3. 2	0.197mm	Model-5 .3. 2	0.242mm
Model-1 .3. 3	0.095mm	Model-2 .3. 3	0.169mm	Model-3 .3. 3	0.236mm	Model-4 .3. 3	0.267mm	Model-5 .3. 3	0.324mm
Model-1 .4. 1	0.034mm	Model-2 .4. 1	0.070mm	Model-3 .4. 1	0.093mm	Model-4 .4. 1	0.112mm	Model-5 .4. 1	0.156mm
Model-1 .4. 2	0.060mm	Model-2 .4. 2	0.106mm	Model-3 .4. 2	0.152mm	Model-4 .4. 2	0.180mm	Model-5 .4. 2	0.229mm
Model-1 .4. 3	0.086mm	Model-2 .4. 3	0.161mm	Model-3 .4. 3	0.221mm	Model-4 .4. 3	0.268mm	Model-5 .4. 3	0.326mm
Model-1 .5. 1	0.029mm	Model-2 .5. 1	0.065mm	Model-3 .5. 1	0.104mm	Model-4 .5. 1	0.103mm	Model-5 .5. 1	0.132mm
Model-1 .5. 2	0.056mm	Model-2 .5. 2	0.113mm	Model-3 .5. 2	0.179mm	Model-4 .5. 2	0.148mm	Model-5 .5. 2	0.206mm
Model-1 .5. 3	0.084mm	Model-2 .5. 3	0.181mm	Model-3 .5. 3	0.239mm	Model-4 .5. 3	0.215mm	Model-5 .5. 3	0.264mm
Model-1 .6. 1	0.013mm	Model-2 .6. 1	0.076mm	Model-3 .6. 1	0.119mm	Model-4 .6. 1	0.119mm	Model-5 .6. 1	0.149mm
Model-1 .6. 2	0.076mm	Model-2 .6. 2	0.140mm	Model-3 .6. 2	0.193mm	Model-4 .6. 2	0.197mm	Model-5 .6. 2	0.238mm
Model-1 .6. 3	0.113mm	Model-2 .6. 3	0.190mm	Model-3 .6. 3	0.267mm	Model-4 .6. 3	0.272mm	Model-5 .6. 3	0.321mm
Model-1 .7. 1	0.031mm	Model-2 .7. 1	0.069mm	Model-3 .7. 1	0.090mm	Model-4 .7. 1	0.116mm	Model-5 .7. 1	0.138mm
Model-	0.060mm	Model-2 .7.	0.124m	Model-3 .7.	0.115m	Model-4 .7.	0.197m	Model-5 .7.	0.232mm

1 .7. 2		2	m	2	m	2	m	2	
Model-1 .7. 3	0.090mm	Model-2 .7. 3	0.168mm	Model-3 .7. 3	0.135mm	Model-4 .7. 3	0.268mm	Model-5 .7. 3	0.321mm

106 models were used for this study. The specifications of the models and the amount of wear of each are shown in Table 2 and 3. For example, the amount of wear in model-1.1. 1(lower material: indirect composite, upper material Zirconiya and applied load 25N (Ttable 2)) is equal to 0.012mm

RESULTS AND DISCUSSION

The present study conducted reciprocating tests to identify the wear behavior of five antiquated dental materials: direct composites (e.g., Nanohybrids, micro hybrids); indirect composites (e.g., BelleGlass); and ceramics (e.g., feldspathic porcelain, resin Nanoceramics). The tested wear tracks were observed by an optical microscope (Fig. 4). Test results indicate that some materials are more susceptible to wear than others. The wear mechanism, as predicted, appears to be abrasive due to its Low hardness compared to the zirconia ball (Fig. 4).

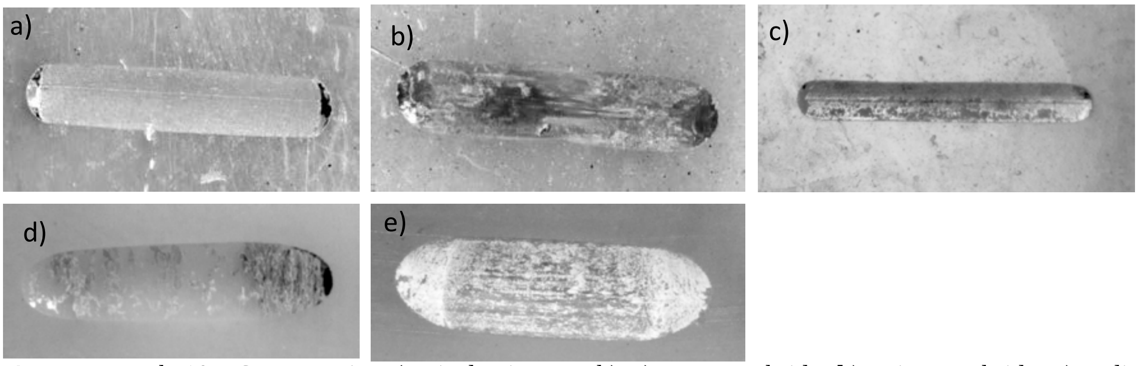


Fig.4. Wear Track 10x Cross section (optical micrograph) **a)** Nano Hybrids, **b)** Micro Hybrids, **c)** Indirect Composites, **d)** Resin Nano Ceramics, **e)** Feldespatics.

The wear track on the Nanohybrid sample was smooth and free of chips or particles. A variety of shades and colors on the wear track of the micro-hybrid sample suggests that heat generated during the test may have affected the chemical composition of the sample (Fig. 4. b). Even the smallest chemical composition change to a thin layer on the sample surface can increase the wear of the material.The narrow wear track on the indirect composite sample indicates less wear (Fig. 4. c). The wear track also exhibits a grouping of black points, which can be explained by the three-part abrasive wear mechanism. During this process, compression of the zirconia ball onto the sample's surface causes particle separation, which can appear as dark points to the observer.

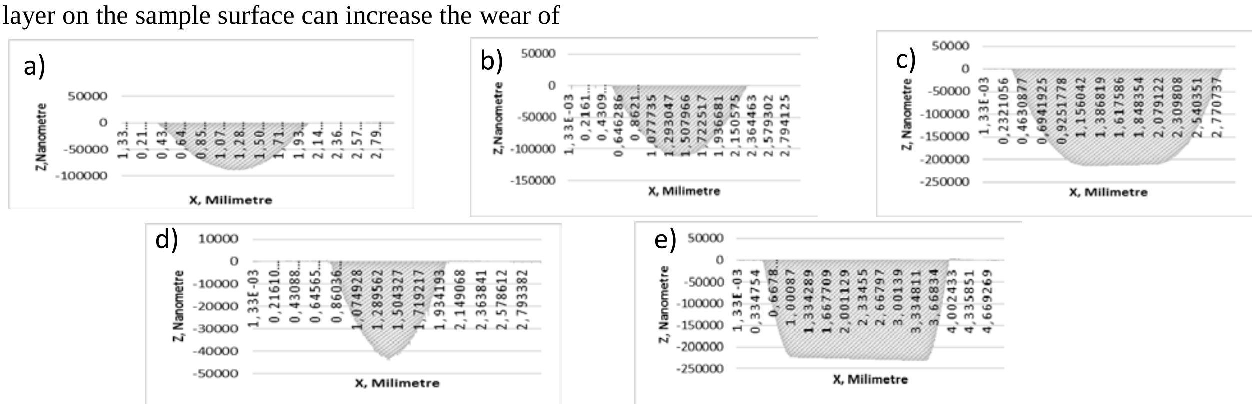


Fig.5. Wear a cross-sectional area. a)nanohybrid, b) micro-hybrid, c)indirect composite, d)resin nano-ceramic, e) feldspathic

The wear track of resin Nanoceramics is visibly broad, which suggests a lower wear resistance. Multiple areas on the wear track exhibit a variety of colors, indicating the depth of wear on the sample's surface. Furthermore, pieces of the sample's surface were removed and then reattached, which implies that the main wear mechanism in resin Nanoceramics is adhesive. Finally, the wear track of the feldspathic sample was covered by bright white particles, which were a product of the adhesive wear mechanism. Exhibiting the same adhesive wear mechanisms, the resin Nanoceramics sample and the feldspathic sample experienced the highest volume of loss during the wear tests. After testing, the specimens were scanned by Roddenstock RM 600 laser stylus. The volume of wear was calculated using cross-sectional data of the wear tracks (Fig.5). The highest wear volume is assigned to the feldspathic sample, which incidentally exhibited the lowest wear resistance. The indirect composite sample displayed the lowest wear volume and the highest wear resistance. In terms of friction, the lowest friction coefficient (4.4) was observed in the indirect composite sample, while the highest (0.8) belonged to the feldspathic sample, mainly due to its adhesive wear mechanism.

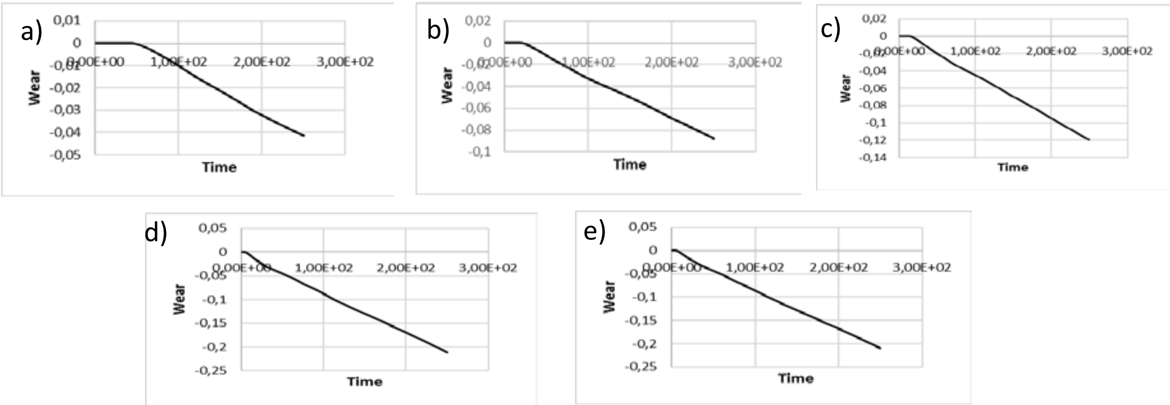
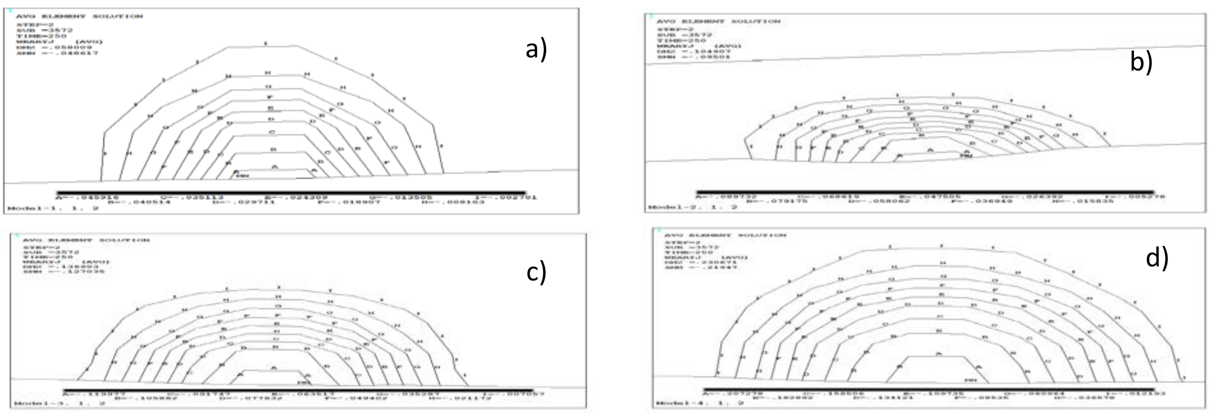


Fig.6. Wear behavior. a)indirect composite, b)nanohybrid, c)micro-hybrid, d)feldspathic, e)resin nano ceram

Best results of all 115 Model showed in Table 4 that shows the best relation of lower and upper materials According to Fig. 7 from ANSYS analyses, the wear value in indirect composites are minimum, and the value is maximum in feldspathic. Both experimentaland analyses calculation have near verification.Fig. 7 show the wear values in contact regions for each material that obtained from ANSYS program pakage. The wear distribution in the A-I (A shows maksimum and I Shows minimum values) ranges has been shown.

Table 4- Relations between upper and lower materials

Lower Material	Best upper material for load 25N	Best upper material for load 50N	Best upper material for load 75N
Indirect Composite	Zirconia	Zirconia	Enemal
Nanohybrids	Zirconia	Zirconia	Nanohybrids
Micro hybrids	Zirconia	Resin nanoceramics	Resin nanoceramics
Feldspatics	Feldspatics	Feldspatics	Feldspatics
Resin nanoceramics	Micro hybrids	Micro hybrids	Micro hybrids



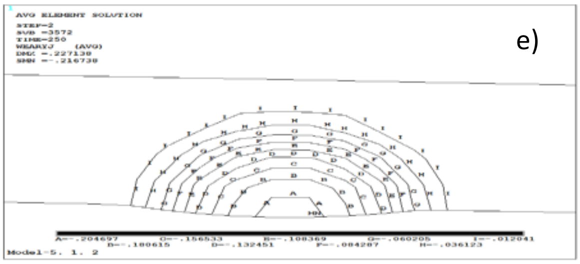


Fig.7. Wear value. a) indirect composite, b) Nanohybrid, c) micro hybrid, d) feldspatic, e) resine nano ceramic

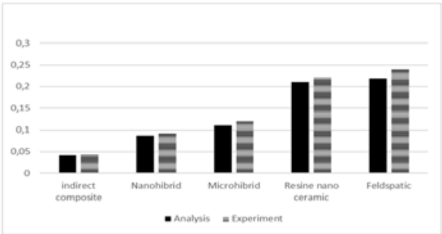


Fig. 8. Wear value experiment vs. analysis

CONCLUSION

Results of the study suggest that compared to ceramics, the composite materials are influenced less wear. Additionally, results indicate that less elastic modulus, larger contact area, and fewer contact stresses it leads, also materials which have high amounts in failure-strain are more resilient to fatigue (Table 1). As filler particles have dissolved, not only do they lead to three-body abrasion, but also quicken the rate of wear. By entrapping the debris in antagonist and material surface; meanwhile, the self-abrasive effect gets greater, the composite filler particles get harder and larger. Contact winds up changeless when flotsam and jetsam are captured between the enemy and material surface; along these lines, the bigger and harder the composite filler particles, the more prominent the self-grating impact.

From a clinical view, wearing in a tooth is resulted from a combination of two- and three-body wear, and is compounded by patient-related factors such as nutrition, para functions, and other antagonists. Given these variations, a direct association between two different wear tests, Vivo and Vitro, maybe impossible. As it relates to this study, understanding the mechanism of wearing in and to vigorous restorative materials according to wear resistance is the main goal of in vitro studies on wear. Results of the present tests suggest that ceramic materials such as feldspathic and resin Nanoceramics have less wear resistance than direct and indirect composites. In dentistry, tribological behavior like the wearing down of teeth and restorative materials is a particularly significant clinical problem. Wear is an important consequence of occlusal interaction and, if not controlled, can lead to poor masticatory function and various treatment problems, ultimately resulting in reduced quality of life and the possible deterioration of overall health. Consequently, tribology of dental materials, which deals with understanding the mechanisms and controlling factors in dental wear, is critically important. Almost no attempt has been made to model tribological behavior in dentistry; however, because of the intricacy of the oral area and some functions regarding biomechanical, modeled dental tribology has been proposed (Antunes P. V. and Ramalho A., 2003). Although simple models may not provide a completely accurate representation of dental wear and function, they can be useful in comparing and contrasting the roles of oral lubrication, friction, and wear Bahrami (M. et al., 2005). Despite the involvement of tribology in subjects such as dentistry, material science, and engineering, its role in terms of dental materials is still inadequately understood Lewis R. and Dwyer-Joyce R. S., (2005). Even though much progress has been made, much remains to be done. Collaboration among clinical dentists, materials researchers, and tribologists will advance this critical area of research (Marinov V., 2022).

In this research, in addition to laboratory studies, numerical analysis as well as design in finite element software was performed (Branco A. C., 2022). Compared to similar research, it has more human samples as well as more numerical evaluations. Using the results of the analyzes obtained in this work, better materials with higher abrasion strength can be produced that will eventually have a longer life and more durability. The environment of dental wear in the mouth is a complex environment with many variables, most of which have been considered in this study. For this reason, it can be a basis for better work in the future (Laborie M., 2022)

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