



Effect of SiO₂ and Al₂O₃ nanoparticles on wear resistance of PMMA acrylic denture teeth

Efeito das nanopartículas de SiO₂ e Al₂O₃ na resistência ao desgaste de dentes em acrílico PMMA para prótese

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ABSTRACT

Objective: This study aimed to evaluate the wear resistance of acrylic denture teeth containing silicon dioxide (nano-SiO₂) and aluminum dioxide (nano-Al₂O₃) nanoparticles. **Material and Methods:** Poly methyl methacrylate (PMMA) denture tooth material was used to denture tooth material was used to fabricate 84 specimens ($n=10$) containing nano-SiO₂ and nano-Al₂O₃ in concentrations 0.1wt%, 0.3wt%, and 0.5wt% of acrylic powder. A two-body wear testing machine and digital microscope were used to measure the changes in weight loss and surface roughness respectively. One-way ANOVA and pair-wise Tukey's post-hoc tests were used for data analysis ($\alpha = 0.05$). **Results:** Nano-SiO₂ modified teeth material demonstrated a significant increase in weight loss in comparison conventional artificial acrylic teeth material ($p < 0.05$) while nano-Al₂O₃ modified teeth material demonstrated non-significant increase in weight loss except for 0.5% subgroup ($p < 0.05$). There is no significant differences regarding roughness change after wear simulation among all tested groups ($p > 0.05$). **Conclusion:** Nano-Al₂O₃ nanoparticles exhibit less negative effect than nano-SiO₂ so; it could be used with caution if necessary.

KEYWORDS

Acrylic denture teeth; Al₂O₃ nanoparticles; SiO₂ nanoparticles; wear resistance; surface roughness.

RESUMO

Objetivo: Este estudo teve como objetivo avaliar a resistência ao desgaste de dentes em acrílico para próteses contendo nanopartículas de dióxido de silício (nano-SiO₂) e dióxido de alumínio (nano-Al₂O₃). **Material e Métodos:** O material em polimetilmetacrilato (PMMA) foi utilizado para fabricar 84 amostras ($n=10$) contendo nano-SiO₂ e nano-Al₂O₃ nas concentrações 0,1% em peso, 0,3% em peso e 0,5% em peso de pó acrílico. Uma máquina de teste de desgaste de dois corpos e um microscópio digital foram usados para medir as mudanças na perda de peso e rugosidade da superfície, respectivamente. Testes de ANOVA a um fator e testes de comparações múltiplas de Tukey foram utilizados para análise dos dados ($\alpha = 0,05$). **Resultados:** O material modificado com nano-SiO₂ demonstrou um aumento significativo na perda de peso em comparação com o material acrílico artificial convencional ($p < 0,05$) enquanto o material modificado com nano-Al₂O₃ demonstrou aumento não significativo na perda de peso, exceto no subgrupo 0,5% ($p < 0,05$). Não há diferenças significativas em relação à alteração da rugosidade após a simulação de desgaste entre todos os grupos testados ($p > 0,05$). **Conclusão:** As nanopartículas de nano-Al₂O₃ exibem menos efeito negativo que o nano-SiO₂, podendo ser usado com cautela, se necessário.

PALAVRAS-CHAVE

Dentes de prótese em acrílico; Nanopartículas de Al₂O₃; Nanopartículas de SiO₂; resistência ao desgaste; rigidez da superfície.

INTRODUCTION

To fabricate removable complete and partial dentures, artificial teeth with superior surface properties are often necessary for prosthodontics rehabilitation. Wear resistance of artificial teeth's material is recommended to maintain the correctly established occlusal vertical dimension and enhance chewing efficiency [1,2]. There are two types of artificial teeth, acrylic and porcelain teeth. Although porcelain teeth have greater hardness, better color stability, exhibit superior resistance to wear than acrylic teeth, they possess some disadvantages such as insufficient bonding to denture base, brittleness, clicking and opposing natural teeth abrasion [3,4].

Acrylic resin teeth were introduced in the early 1930s and are widely used for dentures fabrication because the process is simple and low cost compared to porcelain teeth. Acrylic teeth solved some of porcelain denture teeth's problems, including better bonding to denture base, less brittleness, reduction of chewing noises, ease of being re-contoured and being re-polished and more natural appearance [5], however, low wear resistance was still a major concern, since acrylic denture teeth can go through rapid change in occlusal morphology in a short period of time [3].

The longevity of removable prostheses is dependent on the wear resistance of the artificial teeth [1]. Wear resistance is defined as the ability of material to withstand mechanical actions such as rubbing, scraping, or erosion which tend progressively to remove material from its surface. It was reported that the vertical wear of denture teeth was patient-specific between 0.2 to 1.0 mm in two years. Therefore, teeth with insufficient wear resistance resulted in the loss of vertical dimension, reduced masticatory efficiency, craniofacial disorder, increase patients' discomfort and esthetic impairment leading

to limitation of acrylic teeth [2]. To improve the efficiency of acrylic teeth with acceptable wear resistance, many trials had been carried out to improve the wear resistance of acrylic teeth; using of metal occlusal surfaces, amalgam stops, or gold occlusal surfaces in resin posterior teeth, or using of composite occlusal surfaces, while other suggested modification of acrylic resin teeth with cross-linking agents [6,7]. Crosslinking agents were added to the PMMA material to allow for an increased crosslinking between the linear polymeric chains, leading to a highly dense structure with improved hardness and crazing resistance[1,3,8]. However, the bond strength between cross-linked acrylic resin teeth and the denture base is poor compared to conventional acrylic resin teeth [9].

New types of acrylic resin teeth with inorganic fillers and nanofilled composite resin acrylic teeth have been developed specifically to provide increased wear resistance [3,4,6,7]. Stober et al studied the wear behavior of newly developed denture teeth with nanofillers and found that teeth with inorganic fillers demonstrated significantly lower wear values than conventional or cross-linked acrylic resin teeth without fillers [4]. Moreover, Loyaga-Rendo et al. [8] studied the compositional structure of composite rein artificial teeth and reported that the properties of filled polymers were influenced by the quantity of filler content and the size and geometry of the filler particles.

The new nano-hybrid composite consists of a combination of urethane dimethacrylate matrix with three different fillers and PMMA clusters embedded in the structure aiming to strengthen the matrix and increase the material's hardness and wear resistance. However, nano-hybrid composite denture teeth exhibited statistically significantly more wear than the interpenetrating polymer network (IPN) and double crosslinking PMMA

denture teeth [1]. Further modifications of acrylic denture teeth with nanofillers and their interfaces within resin matrix still growing for the production of nano-composite resin teeth with superior surface properties such as; less staining, high wear resistance, and polishability [3-5].

Incorporating nanoparticles within different dental materials resulted in nanocomposites with superior properties [10,11]. Amongst commonly used nanoparticles; silicon oxide (nano-SiO₂) and aluminum oxide (nano-Al₂O₃) nanoparticles. [10] Nano-SiO₂ is usually filler used in dental materials such as composite, glass ionomer cement, some adhesive systems, ceramics, and tooth pastes [12]. Alnanmel et al. [13], evaluated the effect of addition of nano-SiO₂ on some properties of PMMA and reported a highly significant increase in impact and transverse strength. Balose and Sonyet al found that the addition of nano-SiO₂ enhanced the microhardness and fracture toughness of PMMA. It was also found that the properties of specimens with low nano-SiO₂ content were improved more than the specimens with high nano-SiO₂ content [12].

Nano-Al₂O₃ is one of the most versatile ceramic oxides employing unique properties such as high elastic modulus, thermal and chemical stability, high strength and toughness. Nano-Al₂O₃ has received considerable attention and has been historically well accepted as biomaterials for dental and medical applications [14]. Nano-Al₂O₃ possesses interatomic bonding, giving rise to its desirable material characteristic. Its high hardness, excellent dielectric properties, refractoriness and good thermal properties make it the material of choice for wide range of application [15,16]. Jasim et al. [17], investigated the effect of nano-Al₂O₃ on some mechanical and physical properties of PMMA with three different concentration 1wt%, 2wt%

and 3wt% nano-Al₂O₃. The results showed that Al₂O₃ nanoparticles with concentration 1% and 2% increased the transverse strength of PMMA, while nano-Al₂O₃ with different concentrations did not have significant effect on the surface roughness of PMMA [17].

Nano-SiO₂ and nano-Al₂O₃ had significant improving effect on some properties of PMMA, however there were little data available regarding their effect on the wear resistance of PMMA acrylic denture teeth, so further investigations were needed. The null hypothesis of this study was that the incorporation of nano-SiO₂ and nano-Al₂O₃ into PMMA denture teeth would have no effect on the wear resistance of acrylic resin denture teeth.

MATERIAL AND METHODS

Preparation of specimens

A total number of standardized 84 rectangular-shaped specimens were prepared from heat cured tooth shade acrylic resin (Acrostone, Acrostone dental factory, Cairo, Egypt) using metal molds in dimensions (12x10x2.2 mm) according to ISO/TS 14569-2.[18] Each metal model was invested in hard dental stone after painting it with separating medium to allow easy removal from the die then was allowed to set. After complete set of the stone, the flasks were opened and metal molds were removed creating mold spaces.

PMMA / nanoparticle composite preparation

Nano-SiO₂ and nano-Al₂O₃ (7-35nm, Sigma Aldrich, Germany) were prepared (Nano Tech Egypt for Photo-Electronics, Cairo, Egypt.) then weighed using electronic analytical balance (Sartorius, Biopharmaceutical and Laboratories, Germany) to be added separately with the concentrations 0.1, 0.3, and 0.5 wt.% of polymer powder using mechanical

mixer to ensure even distribution of nanoparticles. According to of nanoparticle type, the specimens were divided into 3 groups; two groups and nanoparticles with one group without nanoparticles as control. The two nanoparticles incorporated groups S, and A were divided into 3 subgroups according to the concentration of nanoparticles (Table I) incorporated into the acrylic powders.

Table I - Specimens grouping and specifications according to nanoparticles concentrations.

Group	Subgroup and code	Material specifications
(C)	Control	Unmodified resin teeth specimens
(S) nano-SiO ₂ group	Sg1	specimen reinforced with 0.1% nano-SiO ₂
	Sg2	specimen reinforced with 0.3% nano-SiO ₂
	Sg3	specimen reinforced with 0.5% nano-SiO ₂
(A) nano-Al ₂ O ₃ group	Ag1	Specimen reinforced with 0.1% nano-Al ₂ O ₃
	Ag2	specimen reinforced with 0.3% nano- Al ₂ O ₃
	Ag3	specimen reinforced with 0.5% nano- Al ₂ O ₃

Specimens processing

According to the manufacturer's instructions, polymer to monomer ratio (2.5:1 by weight) of denture teeth material was mixed and kept aside until reaching the dough stage. After separating medium application to all stone surfaces, the acrylic dough was packed into the mold spaces then the flask was closed under pressure using pneumatic press. After 30 minutes, the curing process was carried out by flask immersion into water at 74 °C was maintained for 1.5 h then water bath temperature was brought to 100 °C and allowed to boil for 1 hour. After processing, the flask was left on the bench to allow it to be cold at room temperature. Then the flask was opened and the acrylic specimens were removed from the flask. After complete polymerization, all specimens were finished using a tungsten carbide burs (HM79GX-040-HP; Meisinger, Centennial, CO) at 18,000 rpm to remove any excess resin followed by finer

rubber polishing tips (FINOPOL Polishers, 64830, LABOSHOP GmbH, Germany). For surface standardization, specimens were further polished using a polishing cloth disc (TexMet C10in, 42-3210, Buehler GmbH) and mechanical polisher (Metaserve 250 grinder-polisher, Buehler) at 100 rpm for 5 minutes in wet conditions. A digital caliper (Mitutoyo, Japan) was used to confirm the dimensions of polished specimens and specimens with proper dimensions were stored in distilled water 37 °C for 48 h prior to testing.

Evaluation of baseline measurements (before wear simulation)

Weight measurement (W1)

Each specimen was weighed using the electronic analytical balance (balance fully automated calibration technology and a micro weighing scale) with an accuracy of 0.0001 to weigh the difference in weight before and after wear simulation for 37,500 cycles. Each specimen was cleaned and dried with tissue paper before weighing. To ensure accuracy, the balance was kept on a free standing table at all times, away from vibrations and weighed the specimen with the glass doors of the balance closed to avoid the effect of air drafts.

Surface roughness measurements (Ra1)

Each specimen was photographed using USB digital microscope with a built-in camera (Scope Capture Digital Microscope, Guangdong, China) connected with an IBM compatible computer before wear simulation using a fixed magnification of 120X. The images were recorded with a resolution of 1280×1024 Pixels/Image. Digital microscope images were cropped to 350 x 400 pixels using Microsoft office picture manager to specify/standardize area of roughness measurement. The cropped images were analyzed using WSxM software [19]. A 3D image of the

surface profile of the specimen was created using a digital image analysis system (Image J 1.43U, National Institute of Health, USA). 3D images were collected for each specimen and mean was calculated by averaging three reading on each specimen.

Wear testing

The 2-body wear testing was performed using chewing simulator (Model Ach-09075Dc-t, AdTech co Ltd, Germany) integrated with thermo-cyclic protocol operated on servo-motor. Each chamber of the chewing simulator consists of an upper antagonist holder that can be tightened with a screw to mount the natural tooth and a lower plastic specimen holder to hold the specimen. Each specimen was mounted inside the lower plastic specimen holder of chewing simulator for wear simulation. Wear simulation of each specimen was carried out till 37,500 cycles to simulate three months of clinical function [4,20]. The parameters of the wear test are listed in table II.

Table II - Wear test parameters.

Subgroup and code	Marital specifications
Cold/hot bath temperature: 5°C/55°C	Dwell time: 60 s
Vertical movement: 1 mm	Horizontal movement: 3 mm
Rising speed: 90 mm/s	Forward speed: 90 mm/s
Descending speed: 40 mm/s	Backward speed: 40 mm/s
Cycle frequency 1.6 Hz	Weight per specimen: 700mg

Evaluation of measurements after wear simulation.

Weight measurements (W2)

After wear simulation each mounted specimen was ultrasonically cleaned and dried with tissue paper before weighing. Each specimen was weighed again after wear simulation using the electronic analytical balance. The difference in weight measurements between the weight of specimen

before and after wear simulation determined the weight loss. The amount of the weight loss of each specimen was used to evaluate the amount of wear that occurs in each specimen according to equation $W_{loss} = W1 - W2$ [3,6].

Roughness Measurements (Ra₂)

After wear simulation, each specimen was photographed as measured before. The unworn surface served as a reference. With this method, a 3-dimensional geometry of the worn surface was generated. The change in surface roughness measurements before and after wear simulation was determined for each specimen according to equation $Ra = Ra_1 - Ra_2$ [2].

Data analysis was performed in several steps. Initially, descriptive statistics for each group results. One-way-ANOVA followed by pair-wise Tukey's post-hoc tests was performed to detect significance among groups. Two-way-ANOVA and t-test for subgroups were performed for comparing the effect of modification and concentration of nano-fillers on weight loss and surface roughness. Statistical analysis was performed using Asistat 7.6 statistics software for Windows (Campina Grande, Paraiba state, Brazil). *P*-value ≤ 0.05 was considered statistically significant.

RESULTS

Mean values and standard deviations (SD) of weight loss for nano-SiO₂-modified group were summarized in table III. The difference between S subgroups and C group was statistically significant as indicated by ANOVA test ($F = 16.5$, $p < 0.05$). Pair-wise Tukey's post-hoc test showed that the difference between S subgroup was statistically non-significant ($p > 0.05$). The results revealed that wear in each of the 3 subgroups of nano-SiO₂-modified resin teeth was significantly higher than wear of unfilled acrylic resin teeth (-0.0002 ± 0.0002 gm). Between silica

modified groups, the highest weight loss mean value after wear simulation for Sg1 is 0.00118 ± 0.00006 gm while the lowest weight loss mean value for Sg2 is -0.00103 ± 0.0002 gm.

Mean values and SD of weight loss for nano-Al₂O₃-modified group were summarized in table IV. The difference between A subgroups and C group was statistically non-significant except Ag3 as indicated by ANOVA test ($F = 20.4$, $p < 0.05$). Pair-wise Tukey's post-hoc test showed that the difference between Ag1 and Ag2 was statistically non-significant ($p > 0.05$). The highest weight loss mean value after wear simulation was recorded for Ag3 (-0.00230 ± 0.0006 gm) while lowest weight loss mean value (-0.0002 ± 0.0002 gm) was for control group.

Table III - Comparison of weight results (Mean values \pm SD) between control (C) and silica modified (S) groups before and after wear simulation.

Groups	Variables	specimen weight		
		Before	After	Weight loss
C		0.365 ± 0.00015	0.3648 ± 0.00005	$-0.0002^A \pm 0.0002$
	Sg1	0.325333 ± 0.00003	0.32415 ± 0.000025	$-0.00118^B \pm 0.00006$
S	Sg2	0.356233 ± 0.00013	0.3552 ± 0.00005	$-0.00103^B \pm 0.0002$
	Sg3	0.349467 ± 0.00018	0.3483 ± 0.00015	$-0.00117^B \pm 0.0003$
ANOVA		Fvalue	16.5	
		Pvalue	<0.0001*	

Same letter indicating insignificant;
* significant ($p \leq 0.05$)
ns; non-significant ($p > 0.05$)

Table IV - Comparison of weight loss results (Mean values \pm SD) between control (C) and alumina modified (A) groups before and after wear simulation.

Groups	Variables	specimen weight		
		Before	After	Weight loss
C		0.365 ± 0.00015	0.3648 ± 0.00005	$-0.0002^A \pm 0.0002$
	Ag1	0.358033 ± 0.0004	0.356967 ± 0.0001	$-0.00107^A \pm 0.00028$
A	Ag2	0.374717 ± 0.006	0.37385 ± 0.005	$-0.00087^A \pm 0.0003$
	Ag3	0.344867 ± 0.0002	0.342567 ± 0.0006	$-0.00230^B \pm 0.0006$
ANOVA		Fvalue	20.4	
		Pvalue	<0.0001*	

Same letter indicating insignificant;
* significant ($p \leq 0.05$)
ns; non-significant ($p > 0.05$)

In Comparison between nano-SiO₂ (S) and nano-Al₂O₃-modified groups (A) regarding weight loss, table V show the pair wise comparisons using t test between the mean of weight loss of S and A subgroups at different concentrations. It was found that the highest weight loss mean value after wear simulation was recorded for 0.5 % modified subgroups followed by 0.1 % modified subgroups weight loss mean while the lowest weight loss mean value after wear simulation was recorded for 0.3 % modified subgroups. The difference was statistically significant as indicated by 2-way-ANOVA ($P = 0.0002$).

Table V - Comparison of weight loss (Mean values \pm SD) between silica and alumina modified groups after wear simulation.

Variables	specimen weight loss		t-test		
	S	A	t-value	P value	
Concentration	0.1 %	-0.00118 ± 0.00006	-0.00107 ± 0.00028	0.8	0.4414ns
	0.3 %	-0.00103 ± 0.0002	-0.00087 ± 0.0003	0.86	0.4098ns
	0.5 %	-0.00117 ± 0.0003	-0.00230 ± 0.0006	3.2	0.009*

*; significant ($p \leq 0.05$)
ns; non-significant ($p > 0.05$)

The mean values and SD for wear measured by roughness average change (Ra in μm) for nano-SiO₂-modified specimens were summarized in table 6. As indicated by ANOVA test ($F = 0.855$, $p > 0.05$), the results illustrated that there is no significant differences regarding roughness change after wear simulation between C and S as well as S subgroups. The highest roughness change mean value after wear simulation was recorded for Sg1 ($0.00346 \pm 0.001 \mu\text{m}$) while lowest roughness change mean value ($0.00107 \pm 0.002 \mu\text{m}$) was Sg3.

Table VI - Comparison of roughness change results (Mean values \pm SD) between control (C) and silica modified (S) groups before and after wear simulation.

Groups	Variables	specimen roughness		
		Before	After	Roughness change
C		0.255567 ± 0.0013	0.257 ± 0.0012	$0.00143^A \pm 0.002$
	Sg1	0.254 ± 0.00005	0.25746 ± 0.0013	$0.00346^A \pm 0.001$
S	Sg2	0.251833 ± 0.0012	0.253683 ± 0.003	$0.00185^A \pm 0.003$
	Sg3	0.255467 ± 0.002	0.256533 ± 0.0002	$0.00107^A \pm 0.002$
ANOVA		Fvalue	0.855	
		Pvalue	0.0823 ns	

Different letter indicating significant;
 *; significant ($p \leq 0.05$)
 ns; non-significant ($p > 0.05$)

The mean values and SD for wear measured by roughness average change (Ra in μm) for nano-Al₂O₃-modified specimens were summarized in table VII. As indicated by ANOVA test ($F = 0.516$, $p > 0.05$), the results illustrate that there is no significant differences regarding roughness change after wear simulation between C and A as well as

A subgroups. The highest roughness change mean value after wear simulation was recorded for Ag2 ($0.00176 \pm 0.0009 \mu\text{m}$) while lowest roughness change mean value ($0.000375 \pm 0.001 \mu\text{m}$) was for Ag1.

Table VII - Comparison of roughness change results (Mean values \pm SD) between control (C) and alumina modified (A) groups before and after wear simulation.

Groups	Variables	specimen roughness		
		Before	After	Roughness change
C		0.255567 ± 0.0013	0.257 ± 0.0012	$0.00143^A \pm 0.002$
	Ag1	0.256725 ± 0.001	0.2571 ± 0.0014	$0.000375^A \pm 0.001$
A	Ag2	0.2558 ± 0.0012	0.25756 ± 0.0013	$0.00176^A \pm 0.0009$
	Ag3	0.25568 ± 0.0016	0.2566 ± 0.00001	$0.00092^A \pm 0.0016$
ANOVA		Fvalue	0.855	
		Pvalue	0.0823 ns	

Different letter indicating significant;
 *; significant ($p \leq 0.05$)
 ns; non-significant ($p > 0.05$)

In comparison between nano-SiO₂ and nano-Al₂O₃-modified groups regarding Ra, table VIII shows the pair wise comparisons using t test between the mean of surface roughness change for S subgroups and A subgroups at different concentrations. Totally it was found that the highest roughness change mean value after wear simulation was recorded for 0.1 % modified subgroups followed by 0.3 % modified subgroups roughness change mean value while the lowest roughness change mean value after wear simulation was recorded for 0.5 % modified subgroups. The difference was not statistically significant as indicated by 2-way-ANOVA ($P = 0.7252$). Figures 1-3 showed the surface characteristic of control group and modified subgroups before and after wear test.

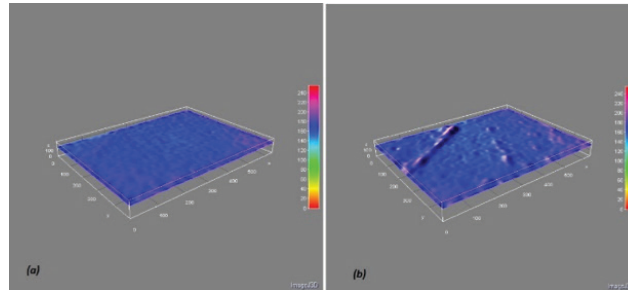


Figure 1 - (a,b) Three dimensional surface topographic features for control group before (a) and after (b) wear simulation.

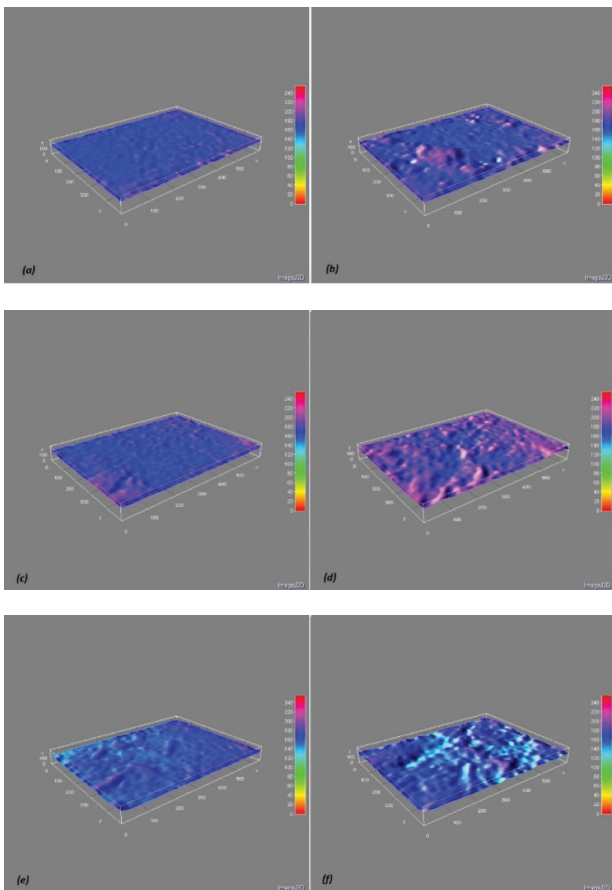


Figure 2 - (a-f). Three dimensional surface topographic features for 0.1 % Silica modified subgroup before (a) after (b) wear; 0.3 % Silica modified subgroup before (c) and after (d) wear; 0.5 % Silica modified subgroup before (e) and after (f) wear simulation.

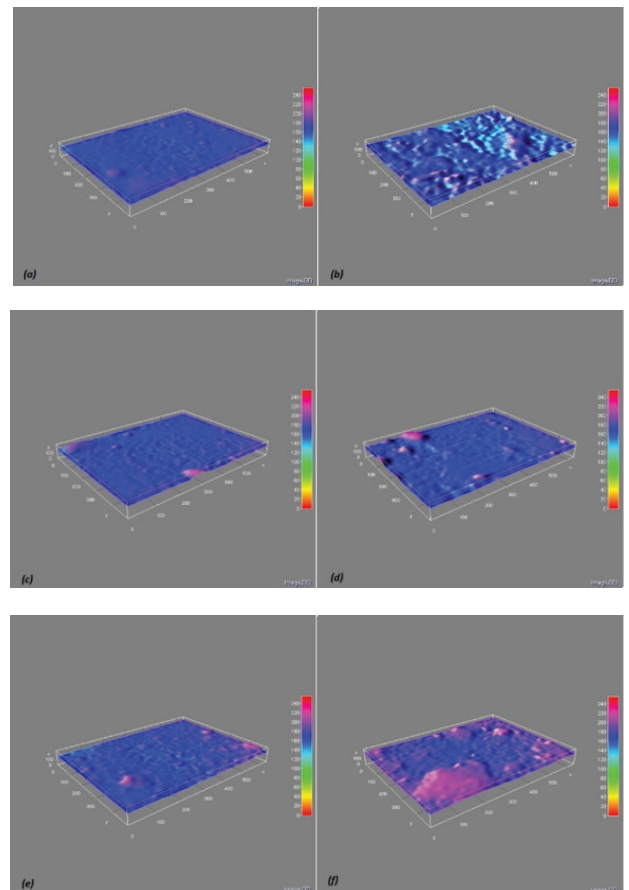


Figure 3 - (a-f). Three dimensional surface topographic features for 0.1% Alumina modified subgroup before (a) and (b) after wear; 0.3% Alumina modified subgroup before (c) and (d) after wear; 0.5% Alumina modified subgroup before (e) and (f) after wear simulation.

Table VIII - Comparison of roughness change (Mean values \pm SD) between silica and alumina modified groups after wear simulation.

Variables	specimen roughness change		t-test		
	S	A	t-value	P value	
Concentration	0.1%	0.00346 \pm 0.001	0.000375 \pm 0.001	2.5	0.0296*
	0.3%	0.00185 \pm 0.003	0.00176 \pm 0.0009	0.0478	0.9626ns
	0.5%	0.00107 \pm 0.002	0.00092 \pm 0.0016	0.116	0.91ns

*; significant ($p \leq 0.05$)ns; non-significant ($p > 0.05$)

DISCUSSION

Wear tests are classified into two-body [9,21,22] or three-body testing methods [4]. Three-body testing usually measures wear characteristics, while the two-body wear testing method shows the effect of direct contact between the specimen and the antagonist. As in the case of complete denture with bilaterally balanced occlusion, the two bodies normally occur during swallowing and parafunctional habits that lead to wear of denture teeth [1]. Therefore, the two-body wear test was selected in current study. The two-body wear study was carried out to evaluate the effect of nano-SiO₂ and nano-Al₂O₃ on the wear resistance of PMMA of denture teeth till 37,500 cycles to simulate three months of clinical function [1,4] using chewing simulator. The material of the antagonist substantially influences the wear rates in two-body wear studies [23,24], therefore, in current study, each specimen was tested against natural tooth to standardize the wear behavior.

The selection of the appropriate type of artificial denture teeth for a particular treatment plan is an important consideration [21]. The low wear resistance of conventional acrylic resin teeth is the major disadvantage that may limit their use [22]. Therefore, micro-fillers or nano-fillers were suggested

to contribute to the durability of the teeth material, which may result in improved physical properties compared to conventional artificial teeth [1,4,6]. The purpose of the current study was to evaluate the wear properties of acrylic denture teeth through the incorporation of nano-SiO₂ or nano-Al₂O₃ into PMMA acrylic teeth material. Wear resistance was evaluated quantitatively by weight loss and qualitatively by surface roughness. The weight loss and surface roughness changes of the modified PMMA artificial teeth were compared in relation to nano-SiO₂ and nano-Al₂O₃ concentrations regarding the degree of wear generated in the wear simulator. Based on the results of the current study, the null hypothesis of this study was rejected, where the incorporation of nano-SiO₂ and nano-Al₂O₃ into PMMA denture teeth significantly affected the wear resistance of modified PMMA denture teeth material.

In the current study, it was found that nano-SiO₂ addition to PMMA denture teeth material with significantly increased the weight loss in comparison to unmodified PMMA denture teeth material. However, no differences within nano-SiO₂ modified subgroups could be found. In spite of the previous studies reported that the nano-SiO₂ [12-15] had significant improving effect on some properties of PMMA, the results of the current study revealed that the nano-SiO₂ decreases the wear resistance of PMMA denture teeth. This decrease in wear resistance could be attributed to the formed loosely attached clusters of nano-SiO₂ on the surface of denture teeth material. These clusters can be detached from the surface of the denture teeth during function and can lead to excessive wear [1].

The results of the present study revealed that no statistical significant differences were found between the weight loss of nano-Al₂O₃ modified experimental subgroups and the weight loss of control group except for

Ag3 subgroup which showed a significant differences ($p < 0.05$). According to this result, nano-Al₂O₃ addition in low concentrations showed less effects on weight loss while in high concentrations, a great weight loss was reported. The weight loss of nano-filler modified resin teeth tested in the current study reported that the material with the highest content of filler showed the highest wear resistance and confirmed by previous studies [4,25,26]. Although previous studies [16,17] reported that nano-Al₂O₃ had significant improving effect on some properties of PMMA, the results of the current study revealed that Al₂O₃ decrease the wear resistance of PMMA denture teeth. A possible explanation for these findings could be the fact that nano-fillers tend to agglomerate into clusters in the micrometer range [4].

Surface roughness changes were used as qualitative evaluation method for wear resistance. The results of this study showed no statistical significant differences among the surface roughness changes of nano-SiO₂ and nano-Al₂O₃ experimental subgroups and the surface roughness changes of control group ($p > 0.05$). The pair-wise comparisons for the surface roughness of the experimental subgroups at different concentration showed statistically significant difference at 0.1 % concentration between silica modified subgroup and alumina modified subgroup ($p < 0.05$), however there was no statistical significant differences at 0.3 % and 0.5 % concentrations between silica modified subgroup and alumina modified subgroup ($p > 0.05$). These results were in agreement with Jasim et al. [17] who reported that there were no significant differences in surface roughness of modified PMMA specimens at different concentrations of nanoparticles. Moreover, previous studies by Jaber [16] and Vojdani et al. [27] reported that the addition of Al₂O₃ in low percentage has no effect on the surface roughness of PMMA.

Although no significance in surface roughness changes was detected, a positive relationship between weight loss and surface roughness changes was observed in the current study. The weight loss increased and surface roughness values increased in relation to nano-filler contents. The results suggest that wear resistance may be influenced not only by the presence or absence of fillers, but also by the type, amount, and size of the nanofillers, as well as by the manner in which the filler particles are integrated into the resin matrix [1,4]. Stober et al. [4] reported that the incorporation of nano-fillers didn't improve the wear resistance of acrylic teeth compared to teeth with traditional fillers. Moreover, Stober et al. [9] reported that there is no any relation between the wear resistance and the chemical composition of the specimens.

This result is contrary to previous reports [3,25], which related the decreased filler particle size and smaller inter-particle spacing between the fillers to improved wear resistance [25]. Suzuki et al. [3] found that the nano-filler composite teeth was harder and having more resistance to wear than acrylic teeth and wear rates of artificial teeth with inorganic fillers are similar to those of human enamel [3]. The controversy between the results of this study and others studies may be attributed to nano-filler type, size, shape, concentrations, and mode of addition as well as the differences in the methodology as wear type, number of specimens, and simulator type used.

In between nano-SiO₂ and nano-Al₂O₃ modified subgroups, the pair-wise comparisons for the weight loss of the experimental subgroups at different concentration showed no statistical significant except that at 0.5% concentration there was statistical significant difference ($p < 0.05$). Comparing the average weight loss between S and A groups, only significance was found with 0.5% addition,

whereas 0.5% nano-Al₂O₃ showed a great weight loss when compared to respective percentage of nano-SiO₂. Hence the results indicated that incorporation of nano-SiO₂ and nano-Al₂O₃ decrease the wear resistance, it is likely that the nanofillers contents, as well as type and size contribute to the wear performance of the individual materials and such as inclusion of nanofillers may not necessarily enhance wear resistance [6,9].

Overall, the wear resistance of the modified denture teeth may be influenced by many factors [23]. The wear process started with the matrix worn and then fillers became exposed and extend from the matrix. Then the fillers detached and removed from the matrix resulted in a new matrix layer, and this process repeats periodically [26]. To enhance the wear resistance of artificial teeth, different methods were suggested such modifications of chemical structure of the resin matrix, adding different fillers and nanofillers, and improve the bonding between nano-filler and resin matrix [26]. Finally, surface treatment of added nano-filler is recommended aiming to improve bonding between nano-fillers and resin matrix. In general, these results revealed that the modifying the PMMA denture teeth by using the SiO₂ nanoparticles or Al₂O₃ nanoparticles leads to decrease the wear resistance without significant changes in the surface roughness of PMMA denture teeth, so it must be used with caution if necessary.

Although the artificial tooth material was maintained under 37 °C flowing water and opposing natural tooth, which simulated the contacting-sliding-separating cycle and represented working tooth surface wear, isn't completely simulating the clinical conditions. Another limitation of this study was that only 1 type of denture teeth material was evaluated. Moreover, the oral environment, dietary

habits, oral hygiene, and neuromuscular force, and parafunctional habits could be contributed to increasing wear. Therefore, this study suggested future work to study the effect of nanoparticles on the physical and mechanical properties of PMMA denture teeth in long term *in vitro*. Additionally, to improve the bonding between nanoparticles and resin matrix, surface treatments of nano-fillers with silane coupling agent is recommended.

CONCLUSION

Within the limitation of this study the following conclusion could be drawn:

1 - The incorporation of nano-SiO₂ and nano-Al₂O₃ into PMMA denture teeth significantly affected the wear resistance of modified PMMA denture teeth material;

2 - The incorporation of SiO₂ nanoparticles or Al₂O₃ nanoparticles into acrylic denture teeth significantly increased the whight loss while there is no significant surface roughness changes of PMMA denture teeth material;

3 - 0.5% Al₂O₃ nanoparticles decrease the wight loss of PMMA denture teeth more than 0.5% SiO₂ nanoparticles. However, 0.1% SiO₂ nanoparticles increasethe surface roughness changes of PMMA denture teeth more than 0.1% Al₂O₃ nanoparticles;

4 - Modifying the PMMA denture teeth by using the SiO₂ nanoparticles or Al₂O₃ nanoparticles may decrease the wear resistance, so the incorporation of nanoparticles should be used with caution if necessary.

Conflict of interest

The authors declare that they have no any conflicts of interest regarding the publication of this paper.

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