

The Effect of Zirconium Oxide Nanoparticle on the Tear Strength of Maxillofacial Silicone

Israa E. Hussein
BDS, (Master student)

Department of Prosthodontic
College of Dentistry, University of Mosul

Radhwan H. Hasan
BDS., MSc, PhD.(Asst.Prof.)

Department of Prosthodontic
College of Dentistry, University of Mosul

الخلاصة

الأهداف: تهدف الدراسة إلى التحقق من تأثير التراكيز المختلفة (0.5%، 1%، 1.5%، 2% بالوزن) من جزيئات أكسيد الزركونيوم النانوية على مقاومة تمزق مادة السيليكون للوجه والفكين المبركن بدرجة حرارة الغرفة. **المواد وطرق العمل:** تم تحضير ما مجموعه (50) عينة باتباع تعليمات التصنيع وقسمت إلى خمس مجموعات (ن = 10). المجموعة أ (المجموعة الضابطة) بدون الجسيمات النانوية، أما المجموعات التجريبية مع أكسيد الزركونيوم النانوية هي المجموعة ب (0.5%)، المجموعة ج (1%)، المجموعة د (1.5%) و المجموعة هـ (2%) عينات مقاومة التمزق تم قياسها بواسطة آلة اختبار شاملة. **النتائج:** كان هناك فرق كبير بين القيم المتوسطة للمجموعات. أظهرت المجموعة الضابطة (21.91 نيوتن / مم) فرقاً غير معنوي مع كل من مجموعة 0.5% (22.46 نيوتن / مم) و مجموعة 2% (23.22 نيوتن / مم)، ولكن فرقاً مهماً للغاية مع المجموعات 1% (25.37 نيوتن / مم) و 1.5% (27.44 نيوتن / مم). بينما أظهرت مجموعة 0.5% ZrO₂ فرقاً معنوياً مع كلتا المجموعتين 1% و 1.5% ZrO₂ ولكن لم يكن هناك فرق معنوي مع 2% ZrO₂. أظهرت مجموعة 1% ZrO₂ فرقاً معنوياً مع مجموعة 1.5% ZrO₂ و فرق معنوي عالي مع مجموعة 2% ZrO₂. لكن المجموعة 1.5% ZrO₂ لها فرق كبير مع المجموعة 2% ZrO₂. **الاستنتاجات:** دمج الجسيمات النانوية ZrO₂ بتركيزات 1%، 1.5% بالوزن أدى إلى تحسين قوة التمزق لمادة السيليكون المبركن في درجة حرارة الغرفة.

ABSTRACT

Aims: The study aimed to investigate the outcome of different concentrations (0.5%, 1%, 1.5%, 2% by weight) of zirconium oxide (ZrO₂) nanoparticle on tear strength of room temperature vulcanized maxillofacial silicone material. **Materials and methods:** A total of (50) samples were prepared following the manufacture instruction and divided into five groups (n=10). The group A (control group) without nanoparticle, group B (0.5% ZrO₂), group C (1% ZrO₂), group D (1.5% ZrO₂), group E (2% ZrO₂). The tear strength samples were measured by a universal testing machine. **Result:** there was a highly significant difference between the groups' mean values. The control group (21.91 N/mm) showed non-significant difference with both 0.5% ZrO₂ group (22.46 N/mm) and 2% ZrO₂ (23.22 N/mm), but a highly significant difference with groups 1% ZrO₂ (25.37 N/mm) and 1.5% ZrO₂ (27.44 N/mm). Whereas the 0.5% ZrO₂ group showed a highly significant difference with both groups (1% and 1.5% ZrO₂), but no significant difference with 2% ZrO₂ group. 1% ZrO₂ group showed a significant difference with 1.5% ZrO₂ group and a highly significant difference with 2% ZrO₂ group. But group 1.5% ZrO₂ has a highly significant difference with group 2% ZrO₂. **Conclusion:** Incorporation of ZrO₂ nanoparticle at 1% and 1.5% by weight enhanced the tear strength of the VST 50F RTV maxillofacial silicone material.

Keywords: Maxillofacial prosthesis; Tear strength; Nanoparticle.

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INTRODUCTION

The maxillofacial prosthesis is utilized for replacing the lost facial parts that have been missing since inherent anomalies, trauma, and tumors. Such a prosthesis's chief objective is the similar creation of lost details, thereby having patients with an ordinary appearance, psychological well-being, and social acceptance ⁽¹⁾.

Materials used to construct maxillofacial prosthesis must have particular ideal properties, such as good tensile strength, tear strength, flexibility, low water sorption, good color stability. Finally, it should be biocompatible ⁽²⁾.

Several materials as wood, wax, metal, ivory, and polymers such as acrylic resins, polyurethane elastomers, and silicone elastomers have been used to construct facial prostheses ⁽³⁾.

Silicone is presented in 1960 till now; it's the most widely used materials in constructing facial prosthesis because of their easiness of handling, flexibility, texture similar to the skin, and biocompatibility ⁽⁴⁾⁽⁵⁾.

Nevertheless, the silicone material has some disadvantages due to its short lifetime, color instability, and silicone deterioration; for instance, it shows altered surface, ill-fitting boundaries due to insufficient tear strength. These variations are in linear relation to the patient's precaution through usage and cleanliness, such as exposure to the disinfectant material besides environmental changes such as tempera-

ture instabilities, UV radiation, air pollution, and moisture ⁽⁶⁾.

Incorporating nanoparticles into the material has become one of the main ways to improve material properties ⁽⁷⁾. Nano-sized particles incorporated into the maxillofacial silicone elastomer to enhance its mechanical properties and viscosities as these particles achieve the mission of supporting the cross-linked polymer by dispersing into the matrix ⁽⁸⁾.

Many types of nanoparticles have been added to silicone material and tested. Such research has confirmed nanosized particle's usefulness in enhancing silicone elastomer's mechanical properties, especially the tear strength ^(5, 8).

The present study aims to assess the impact of Zirconium oxide nanoparticle incorporation on VST-50F RTV maxillofacial elastomers' tear strength property and complete a comparison amongst the different concentrations.

MATERIALS AND METHODS

Zirconium oxide nanoparticle (US research nanomaterials inc., Houston, USA.) incorporated into VST 50F RTV silicone elastomer (Factor II, Inc., Lakeside, AZ, USA) at different concentrations (0.5%, 1%, 1.5%, 2% wt.). Fifty samples were fabricated and separated into five groups, with ten samples within each group. Group A (control group without nanoparticle), group B (0.5% ZrO₂), group C (1% ZrO₂), group D (1.5% ZrO₂) and group E (2% ZrO₂). The tear strength

sample dimension was, according to ASTM D624 (fig 1) ⁽⁹⁾. The dimensions firstly designed using AutoCAD 2015 (Autodesk Inc., San Rafael, CA, USA). Then the Computer-controlled Laser cutting machine (Boye Laser Application Technology Co., Ltd, China) was used to cut spaces in the plastic mold into which the material will pour ⁽¹⁰⁾.

Following the manufacturer's order, the mixing ratio of part A (base) to part B (cross-linker) is 10:1 by weight. Samples for group A the base and cross-linker of silicone weighted by digital electrical balance (0.000 digits, China), then manually mixed for five minutes and tracked by mechanical mixing with vacuum for five min using the Multi-Vac 4 vacuum mixer (Degussa, Frankfurt, Germany) ⁽¹¹⁾.

However, for the experimental groups (B, C, D, E), the nanoparticle was placed into a clean mixing bowl with a clean spatula and weighted by digital electrical balance, then mixed with preweighed base manually for 1min. Followed by mechanical mixing for 10 minutes, the first 3 minutes, the vacuum turned off to prevent nanopowder suction. Then for the remaining 7 minutes, the vacuum turned on to avoid bubbles of air ⁽¹²⁾. before adding the (part B), the mixture was left to stand for approximately two minutes since the mechanical mixer's revolving movement produced heat, which may decrease the working time for the material ⁽¹³⁾.

According to manufacturer instruction, the modified base was mixed with the cross-

linker. The mixture returned to the multi vac 4; vacuum mixer to be mixed mechanically for 5 minutes with the vacuum turned on. To have an accurate result, the mixing of silicone material should be at a controlled temperature of $(23\pm 2^{\circ}\text{C})$ and relative humidity (RH) of $(50\pm 10\%)$ ⁽¹⁴⁾.

The silicone mixture was poured slowly inside the plastic molds' shaped spaces, and the holes should be overfilled with the mix ⁽¹⁵⁾; a few minutes were needed before placing the cover to allow entrapped air bubbles to reach the surface. Now the plastic mold cover gradually and slowly applied to stare from one end to the other one. Once the cover ultimately settled a moderate hand pressure was applied by one hand until the molds' parts were tightened by a screw and nuts in four corners, and the pressure was involved in four sides of the mold using the G clamps (china). According to product information, silicone material was vulcanized at 2-3 hours at $23 \pm 1^{\circ}\text{C}$. in demolding, the sample should be carefully removed from the mold without any strain ⁽¹⁶⁾ then scalpel and blade 10# (Dr. Quillel Surgicals, Pakistan) were used for removing flashes surrounding the sample ⁽¹⁷⁾.

A custom-made lightproof box was used for storing the samples in an air-conditioned room until testing. The temperature was $(10-30^{\circ}\text{C})$, and RH did not exceed 80% ⁽¹⁸⁾. Before testing, the samples were conditioned in controlled temperature and humidity, as mentioned above for 16 h at a minimum ⁽¹⁸⁾. Tear strength

type C samples (Figure. 1) were prepared and tested following ASTM D624 (Ameri-

can Society for Testing and Materials).

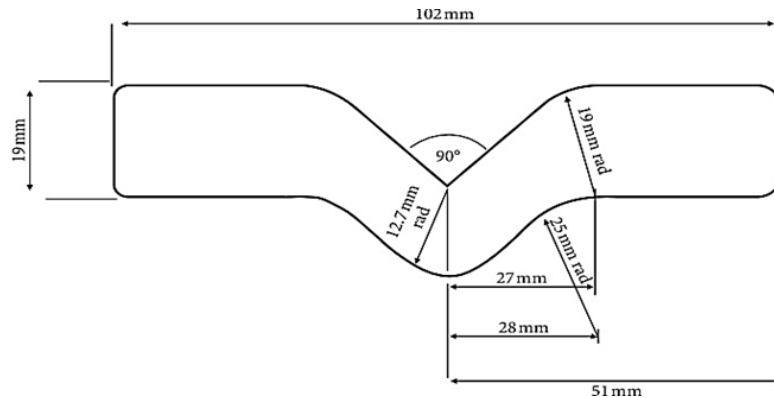


Figure 1: Tear strength test sample (Type C), dimensions in (mm) (ASTM D624).

The samples' flat ends were placed symmetrically in the grips of the universal testing machine AI-3000 (Gotech, China) so that the sample

strained uniformly along its length (Figure 2). the speed of clamps separation was 500 ± 50 mm/min until the sample was ruptured.



Figure 2: sample positioned symmetrically in the grips of the universal testing machine AI-3000.

The tear strength (T_s) was calculated according to ASTM D624 specification : $T = F/D$ (N/mm)

Where:

F : The maximum force recorded at breakage in (N)

D : The median thickness of each sample in (mm)

The data were statistically analyzed using a one-way ANOVA test and post hoc (Tukey HSD). A probability (P) value > 0.05 was considered statistically non-significant, while $P \leq 0.05$ was considered statistically significant, and $P \leq 0.01$ was considered highly significant.

RESULTS

Descriptive statistics of tear strength data for group A (control), group B (0.5 % ZrO₂), group C (1 %

ZrO₂), group D (1.5% ZrO₂) and group E (2 % ZrO₂) shown in (Table. 1).

Table (1): Descriptive statistics of Tear strength (N/mm) among groups.

Groups	No.	Minimum	Maximum	Std. Deviation	Mean
Group A	10	19.90	23.80	1.322	21.91
Group B	10	19.00	24.80	1.853	22.46
Group C	10	23.80	27.00	1.166	25.37
Group D	10	26.00	29.00	.892	27.44
Group E	10	21.00	25.00	1.343	23.22

One-way ANOVA was used to statistically test the tear strength data among groups and showed a highly

significant difference among groups ($P \leq 0.01$) (Table. 2)

Table (2): Statistical test of Tear strength (N/mm) among groups using one-way ANOVA.

SOV	SS	df	MS	F-value	P-value
Between Groups	210.049	4	52.512	28.707	.000 **
Within Groups	82.315	45	1.829		
Total	292.364	49			

SOV: the source of variance; SS: Sum of Squares; df: the degree of freedom; MS: mean square **: highly significant at ($P \leq 0.01$)

Tukey Honestly Significant Difference (Tukey HSD) was conducted to compare mean value among study groups of tear strength data and showed a non-significant difference (NS) at $P > 0.05$, between mean values of group (A) and group (B) and between group (A) and group (E), while a highly significant difference (HS) at $P \leq 0.01$, between group (A) and group (C), group (A) and group (D).whereas

there was a highly significant difference ($P \leq 0.01$) between group (B) and group (C), and between (B) and group (D), but no significant difference($P > 0.05$) between group (B) and group (E).whereas for Group (C) shows a significant difference (S) at $P \leq 0.05$, with a group (D) and a highly significant difference ($P \leq 0.01$) with a group (E). But the group (D) has a highly

significant difference ($P \leq 0.01$) with a group (E), as shown in (Figure.3).

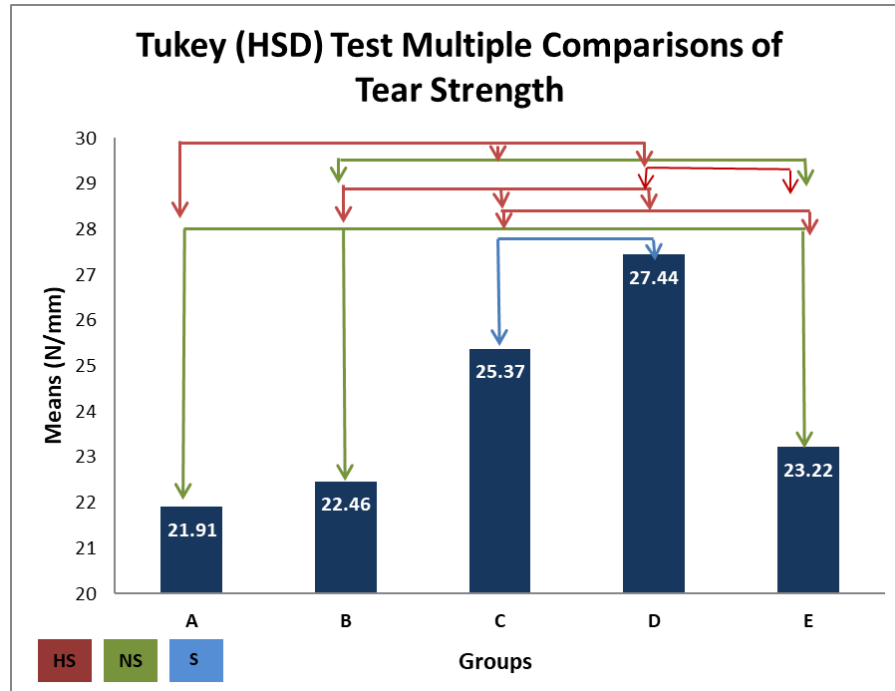


Figure 3: Tukey (HSD) test multiple comparisons of tear strength (N/mm) test mean values between tested groups.

DISCUSSION

Despite their extensive use, they are far away from ideal. Silicone maxillofacial prostheses need replacement due to deterioration in physical and mechanical properties; such problems take many researchers' interest to investigate maxillofacial silicone elastomers ⁽¹⁹⁾.

A tear-strength test indicates an elastomeric material's resistance to rupture when exposed to a tensile force acting upright to a surface flaw ⁽²⁰⁾. the most important property for maxillofacial prostheses is the tear strength, from a clinical point of view ⁽²⁾.

A proliferation in the tear strength of silicone can encourage the high esthetic value of

the facial prosthesis. It allows thinner boundaries, especially in the eye and nose prosthesis, are liable to tearing as the prosthesis is detached from the close facial tissue ⁽²¹⁾.

To reach the amount of reinforcement necessary for good mechanical properties, nanoparticle addition is highly essential. The amount of improvement depends mostly on the quantity of filler loaded, filler characteristics (a specific surface area or particle size, surface activity, and structure), polymer properties, and processing conditions ⁽²²⁾.

The statistical results showed a highly significant increase ($p < 0.01$) in the mean val-

ues of tear strength of VST50F (RTV) silicone elastomers after the addition of 1% and 1.5% ZrO₂ Nanoparticles when related to the control group.

The filled VST 50F RTV maxillofacial silicone's increased tear strengths were closely related to filler's reinforcing effect. Once the nanoparticle is trapped within the polymer matrix, it forms a three-dimensional network due to high surface energy and chemical reactivity, thereby increasing its density. As a consequence, a noticeable increase in polymer toughness and tearing resistance ⁽²³⁾.

Tear strength increase can also be clarified by the polymer's capability to disperse strain energy adjacent to the rising cracks' tip. As tearing extents, nanoparticles will distribute the energy inside the silicone matrix, creating it more unaffected by tearing. A more significant load will be required to entirely breakdown the polymer matrix ⁽²⁴⁾.

Tear strength test results in this study agree with Shakir and Abdul-Ameer ⁽¹²⁾ that the tear strength was improved after the addition of 0.25 wt% TiO₂ to VST50F RTV silicone elastomers.

On the other hand, Tukey (HSD) test multiple comparisons of tear strength mean values result in a no significant difference between mean values of group (A) and groups (B, E), besides, group (B) also showed no significant difference with group E, this explained why the quantity of nano-oxide measured for addition in the silicone elastomer should be at a correct level, ⁽⁸⁾

since too little amount may not be enough for cause changes as for group (B) or in contrast even if the nano-oxide particles might support the silicone matrix but the addition in higher concentration as for group E result in agglomeration of nanoparticles within silicone matrix due to increased surface energy and chemical reactivity of these small-sized nanoparticles ⁽²⁵⁾ resulting in the formation of agglomeration of nano oxides that would result in the tear strength reduction, by performing as stress concentration sites inside the silicone matrix ⁽²⁶⁾. while in contrast to others studies that did not agree with the finding for the present study, which verified that the addition of nanoparticle into RTV silicone elastomers results in a reduction in the tear strength such as wang et al. ⁽²⁷⁾ who added TiO₂ nanoparticle at a concentration of 6% to MDX4-4210 RTV maxillofacial silicone, They reported the reduction in the tear strength of silicone elastomers

Finally, a rational explanation for such variances in the result of studies uses different types of silicone material, the nature of nanoparticle, and the added concentration of nanoparticles.

CONCLUSIONS

Within the limitations of the present study, it was established that the addition of 1% and 1.5% of zirconium oxide nanoparticle results in improved the tear strength of VST-50F (RTV) maxillofacial silicone material.

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