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Original Research Article

The Effects of Hybrid Nano addition on Maxillofacial Silicone Elastomer VST50F Mechanical Properties

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Abstract: ***Purpose*****:** To investigate the effects of hybrid nano (Tio_2 – Al_2o_3) addition on maxillofacial silicone elastomer mechanical properties. ***Methods*****:** A total of 70 samples were prepared and divided into 7 groups; control, 1% Tio_2 (nano-titanium oxides), 2% Tio_2, 1% Al_2o_3 (nano-alumina oxides), 2% Al_2o_3, 0.5% Tio_2-0.5% Al_2o_3, and 1% Tio_2-1% Al_2o_3. which was added to silicone elastomer. Samples were exposed to artificial weathering for 250 hours, then tested for tear strength and roughness tests. The data were analyzed using a one-way ANOVA to determine the differences between groups. ***Results*****:** After artificial weathering, a high increase in the mean value for tear strengths with an acceptable increase in the mean value for roughness was observed in samples containing 2% Tio_2, followed by the samples with a hybrid of 1% Tio_2-1% Al_2o_3, compared to the control and other groups. ***Conclusions*****:** The addition of Tio_2, Al_2o_3, and hybrid nanoparticles addition to maxillofacial silicone improved its mechanical properties. Hybrid nanoparticle filler reinforcement is encouraging for enhancing tear strength and roughness properties values for the longevity of maxillofacial silicone.

Keywords: VST50F Maxillofacial silicone; Nano-alumina oxides; Nano-titanium oxides; Mechanical properties.

1. INTRODUCTION

The most preferred choice for the maxillofacial problem patient is plastic surgery, although artificial reconstruction utilizing alloplastic materials, which is non-invasive and risk-free, can also be used to correct face malformations [1]. Throughout history, a variety of materials have been used to create maxillofacial prostheses, but they still fall short of the optimum material [2]. Bulbulian first described a soft and flexible maxillofacial prosthesis in 1941 [3]. The greatest advancement in the history of facial prostheses was the development of specialized silicone rubber, which posed a significant challenge in the field of craniofacial reconstruction [4, 5].

The addition of fillers, which would increase the material's elasticity and improve its capabilities both physically and mechanically, would make it more useful therapeutically [6]. Other techniques have also been proposed and used to improve the clinical features of maxillofacial silicone elastomers. The impact of introducing nanoparticles to silicone polymer on mechanical and optical properties as well as after exposure to normal and accelerated weathering conditions was investigated in several research [7]. Sonnahalli & Chowdhary's (2020) comprehensive review suggested incorporating nanoparticles (NPs) into silicone elastomers at varying concentrations to enhance their mechanical and physical characteristics, prevent color changing, and maintain stability over the course of their service life [8].

Manufacturers typically provide the mechanical qualities of silicone elastomer without fillers, colors, or additives, which may not accurately reflect the substance's clinical efficacy for extra-oral purposes. Therefore, while employing a material to create facial prostheses, maxillofacial prosthodontists and anaplastologists should be cautious of the manufacturers' specified parameters [1].

The size of the filler particles, surface area, structure, surface activity, and filler concentration all affect how silicone's mechanical properties are improved. Additionally, combining two different microparticle types at a specified percentage may improve the silicone polymers' overall qualities and bring lifelike maxillofacial prosthetics closer to the optimal qualities. As a result, two types of additives were chosen and used in this investigation in varying quantities and with various properties. The additions were microfilters with good flexibility and nanoparticles (NPs) with a high elastic modulus [9]. The qualities of maxillofacial prosthesis materials are being optimized as part of current research to improve the properties of silicone elastomers, which is critical to extending the durability of the prostheses [10].

In this study, VST50F room temperature vulcanized (RTV) maxillofacial silicone was used to investigate the mechanical properties of the maxillofacial silicone subjected to artificial weathering. The VST50F was fabricated with the addition of Tio_2 (nano-titanium), and Al_2o_3 (nano-aluminum) by several weight percentages. The effect of hybrid nanoparticles on the mechanical properties of the maxillofacial silicone was evaluated.

2. MATERIALS AND METHODS

2.1 Material used in this study

The maxillofacial silicone elastomer used in this study was the VST50F RTV (Factor II Inc., USA). Two types of nano-powder used were Tio_2 (nano-titanium oxide), by several weight percentages filler with 99.9% purity and a particle size of 30-50 nm (Platonic Nanotech, Indiana, USA), and Al_2o_3 (nano-alumina oxide) filler (CAS No.1330-060920) with 99.9% purity and particle size of 40-60 nm (Skyspring nanomaterials Inc, USA).

2.2 Mold making

By using a Computer Numerical Control (CNC) system, molds were created in accordance with the requirements of each test. Each mold is made up of identically sized base, frame, and cover components. The surface roughness was tested in accordance with ISO 7619-1 2010 regulations, and the tear strength test was conducted in accordance with ASTM D624 type C standards [9].

2.3 Mixing

According to manufacturer instructions, the mixing ratio of VST50F silicone will be 10:1; for the base (part A) and catalyst (part B). In this study, the amount of base mixed with Tio_2, Al_2o_3, and hybrid nanopowder is shown in Table 1.

The base was first added to the electronic balance container before the catalyst was added and mixed using a vacuum mixer with a speed of 360 rpm and a vacuum (-10 bar). This process was for the control group. For the reinforced groups, the base was added to the electronic balance container first, then the nanopowder was add and the mixture were mixed for three minutes without vacuum before being vacuumed for seven minutes. The catalyst was then added and stirred for the following five minutes under a vacuum [1].

2.4 Pouring and conditioning

The silicone was then injected into the molds using a syringe, and air bubbles on the surface were blown up with a needle. The cover was then tightened using nuts and screws at the mold's corners, and four G-clamps were placed at the middle and sides. The middle of the mold was then placed with a weight of 1 kg. Following that, the closed mold was kept area at (23°C) for around 24 hours to finish the vulcanization of the RTV silicone material in accordance with the manufacturer's instructions [6].

2.5 Samples grouping

A total of 70 samples were prepared and subdivided into 7 groups, 10 samples per group. The groups consist of control without the addition of nanoparticles, 1% Al_2o_3 (nano-alumina), 2% Al_2o_3, 1% Tio_2 (titanium-onan oxides), 2% Tio_2, 0.5% Tio_2-0.5% Al_2o_3, and 1% Tio_2-1% Al_2o_3.

2.6 Tear strength testing

According to ASTM D624 requirements, samples with flat ends and a straight angle in the center were created for the tear strength test. According to ISO 37 requirements, the specimens were tested using a universal testing machine (WDW-20, Laryee Technology Co. Ltd., China) operating at a crosshead speed of 500 mm/min. The machine software was used to calculate the maximum load, and the following equation was used to get the tear strength:

Tear strength = Maximum force at breakage, F (kN) / Thickness of the sample, D (m) [9].

2.7 Surface roughness testing

The samples for the surface roughness test, with a dimension of 25 mm x 25 mm x 6 mm. A profilometer tester was used to measure, and the average of 6 readings was calculated [9].

For the analysis, Statistical Package for the Social Sciences (SPSS) version 26 was used. One-way ANOVA tests were used to show the significant differences among the studied group.

3. RESULTS

The result of tasted mechanical properties for the addition of 1%, and 2% Al_2o_3, by weight to the maxillofacial silicone are compared in Table 2. In comparison to the control group, all groups demonstrated considerably higher mean values for roughness. The mean values for RTV with a 2% Al_2o_3 addition were highest than the control in terms of tear strength, but the mean value for RTV with a 1% Al_2o_3 addition was lowest. The RTV with 2% Al_2o_3 added had the maximum tear strength. RTV, however, produced the greatest mean values for roughness.

The result of tasted mechanical properties of RTV with addition of 1%, and 2%, wt. Tio_2 was compared with control group in Table 3. The tear strength mean values of RTV with 2% Tio_2 added were the greatest compared to the control group. RTV with a 2% Tio_2 addition had a highest mean roughness value than the control group, but RTV with a 1% Tio_2 addition had a lowest roughness value.

Table 4 illustrates the results of the comparison of the mechanical properties of silicone elastomers following reinforcing with hybrid TiO_2 and Al_2O_3 nanoparticle addition. A hybrid of the of Al_2o_3 0.5%- Tio_2 0.5% and $Al_2o_3$1%- Tio_2 1% that add to silicone elastomers provided a higher mean value compared with the control. Both combinations exhibited significantly enhanced mean values for tear strength compared to the control group. Regarding roughness, all combinations produced greater mean values, the addition of Al_2o_3 1%- Tio_2 1% show the highest roughness.

Table 1: The amount of silicone base (part A) mixed with either wt.% Tio_2, Al_2o_3, hybrid nanoparticles and catalyst (part B) for silicone material

Group	Base	Catalyst	Tio_2	Al_2o_3
Tio_2 0% Al_2o_3 0%	100 g	10 g	0 g	0 g
Tio_2 0% Al_2o_3 1%	99 g	9.9 g	0 g	1 g
Tio_2 0% Al_2o_3 2%	98 g	9.8 g	0 g	2 g
Tio_2 1% Al_2o_3 0%	99 g	9.9 g	1 g	0 g
Tio_2 2% Al_2o_3 0%	98 g	9.8 g	2 g	0 g
Tio_2 0.5% Al_2o_3 0.5%	99 g	9.9 g	0.5 g	0.5 g
Tio_2 1% Al_2o_3 1%	98 g	9.8 g	1 g	1 g

Table 2: The comparison of 1%, and 2%, wt. Al_2o_3 addition on VST50F maxillofacial silicone mechanical properties

	Weight Percent (wt.%)	Values Mean ± SD	F Statistic[a] (*df*)	*P* value[a]
Tear (kN/m)	Control	24.06 ± 0.09	97.77 (3;8)	0.000[b]
	1%	24.67 ± 0.30		
	2%	25.77 ± 0.08*		
Roughness (µm)	Control	0.22 ± 0.01	300.44 (3;8)	0.000[b]
	1%	0.29 ± 0.01		
	2%	0.58 ± 0.04*		

[a]One-way ANOVA test

[b] All 2 pairs of mean scores are significantly different by post-hoc test (Scheffe procedure)

Table 3: The comparison of 1%, and 2%, wt. Tio_2 addition on VST50F maxillofacial silicone mechanical properties

	Weight Percent (wt.%)	Values Mean ± SD	F Statistic[a] (*df*)	*P* value[a]
Tear (kN/m)	Control	24.06 ± 0.09	84.08 (3;8)	0.000[b]
	1%	24.98 ± 0.05		
	2%	25.96 ± 0.07*		
Roughness (µm)	Control	0.20 ± 0.01	27.61 (3;8)	0.000 [b]
	1%	0.17 ± 0.02		
	2%	0.49 ± 0.13*		

[a]One-way ANOVA test

[b] All 2 pairs of mean scores are significantly different by post-hoc test (Scheffe procedure)

Table 4: The comparison of hybrid nanoparticles addition on VST50F maxillofacial silicone mechanical properties

	Weight Percent (wt.%)	Values Mean ± SD	F Statistic[a] (*df*)	*P* value[a]
Tear (kN/m)	Control	24.1±0.09	79.12	
	Al_2o_3 0.5% - Tio_2 0.5%	24.6±0.13	(3;8)	0.000[b]
	Al_2o_3 1% - Tio_2 1%	25.9±0.06*		
Roughness (µm)	Control	0.20±0.01	112.6	
	Al_2o_3 0.5% - Tio_2 0.5%	0.15±0.02	(3;8)	0.000[b]
	Al_2o_3 1% - Tio_2 1%	0.29±0.05*		

[a]One-way ANOVA test

[b] All 2 pairs of mean scores are significantly different by post-hoc test (Scheffe procedure)

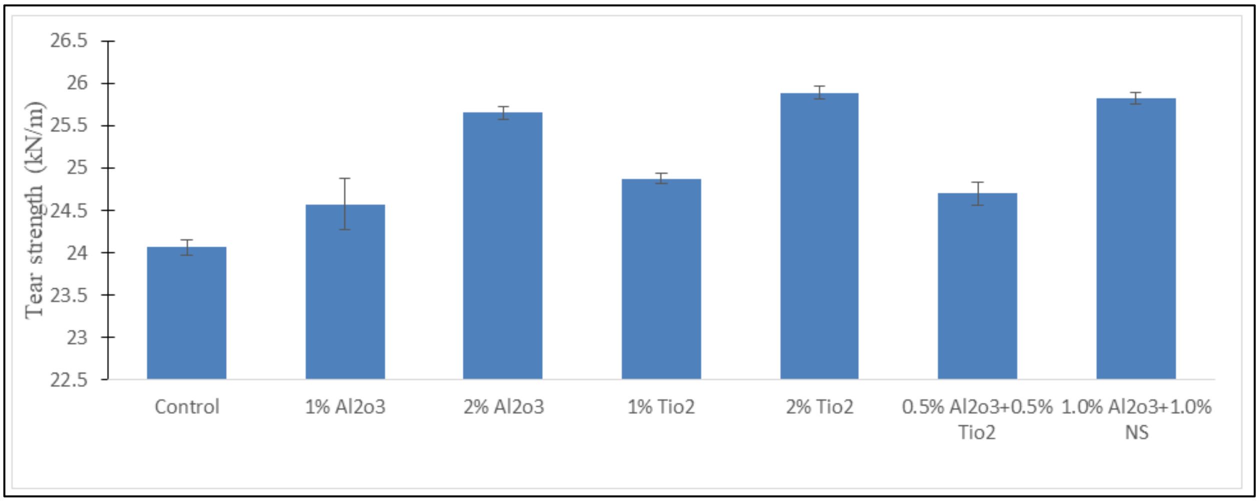

Figure 1: Tear strength for different wt.% of Tio_2, Al_2o_3, and hybrid nanoparticles

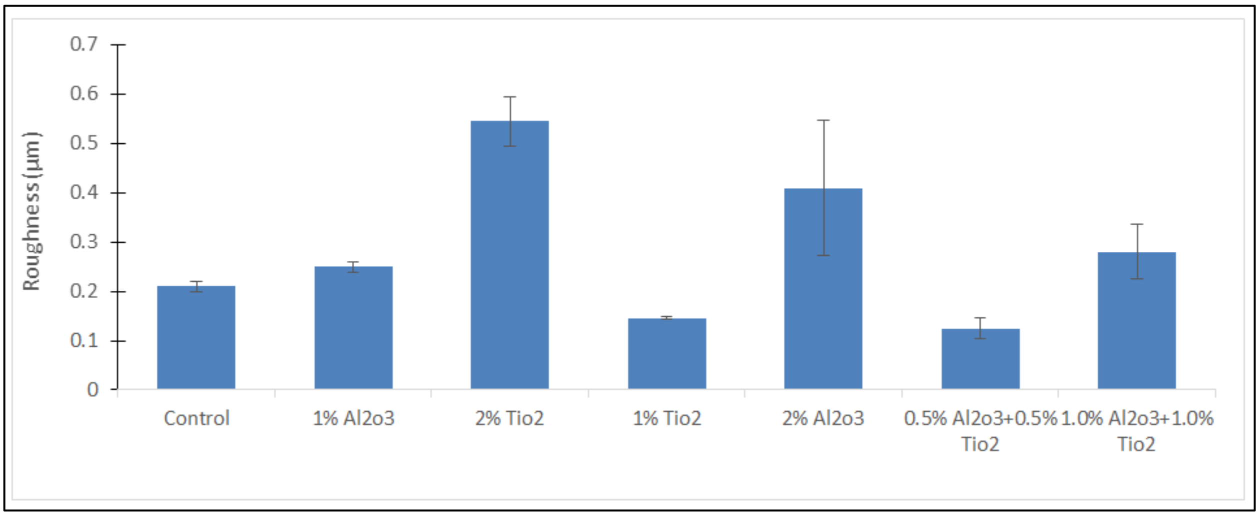

Figure 2: Roughness test for different wt.% of Tio_2, Al_2o_3, and hybrid nanoparticles

4. DISCUSSION

Al_2o_3 and Tio_2 were the two nanofillers chosen for this research because of their superior mechanical and physical properties, high surface area with smaller particle size, chemical activity, affordability, and availability. They are also the most incorporated as a filler in the maxillofacial silicone elastomers, which significantly strengthen maxillofacial silicone properties [11, 12]. A very successful composite was created using the idea of combining nanoparticles (NPs) with polymeric reinforcement as fillers and polymer as a matrix in a new three-phase composite reinforcement [13].

As can be shown in Fig 1, the Tio_2 2% group had the greatest mean value for the tear strength of maxillofacial silicone following reinforcing. In Fig 2, the hybrid nanoparticles group contains 1% Al_2o_3- 1% Tio_2 has the highest mean value. The Al_2o_3 group's highest tear strength was achieved by RTV with 2% Al_2o_3, which was followed by RTV with an addition of 1% Al_2o_3 (Fig 1). This might be because certain polymer chains and silicone's capacity to hold nanoparticles (NPs) could lead to a 3D mesh formation, which might increase the density of silicone elastomer and its resistance to tearing [2]. The polymer chain's intermolecular forces and adsorption on the filler surface both increased as filler concentration increased [9].

The low increase in tear strength at the 1% addition may be due to the small amounts of fillers that act as impurities affecting the polymerization process of the RTV silicone without the formation of a 3D mesh [1].

Roughness test results showed the effect of artificial aging for 250 hours after reinforcing with nanoparticles was significantly increased in RTV with 2% Tio_2 compared to the control group. This result is because nanofiller particles of Al_2o_3 and Tio_2 are strongly affected by the polymeric chain leading to reinforce the polymer. If the particles were separated, they would still be tightly connected to the polymeric chain under various circumstances. It would be assumed that an increase in the polymer porosity would cause an increase in surface roughness, as shown in Fig 2 [9].

The result agreed with other previous studies that used $Tio_{2,}$ fillers reinforcement [14-16]. The result of the current study was also consistent with the results of a study after exposing the silicone prostheses for 12 months [17]. The condition simulated the clinical service, and the conclusion was that all the tested mechanical properties, particularly tear strength were affected negatively. The properties mostly deteriorated to the mixed conditions of light aging and sebum storage. The result of the above-mentioned study contradicted the results of other studies that used Tio_2 and maybe because of different percentages of nanoparticles [18].

However, this pilot study showed disagreement with the outcome of some studies that showed decreased tear strength [19, 20]. Despite the small number of samples applied for each component of these two nanoparticles. This study was able to enhance some mechanical properties of the VST50F silicone polymer and further, after exposure to 250 hours of accelerated weathering conditions. Therefore, we are expecting that the material can produce facial prostheses with longer service in practice.

5. CONCLUSIONS

The best reinforcement that improves the mechanical properties of the VST50F RTV was the 2% Tio_2 group over all other groups. The most suitable percentages of hybrid nanoparticles fillers were found to be 1% Al_2o_3-1% Tio_2, according to this study that enhanced tear strength value while maintaining acceptable values of the roughness properties for silicone (RTV) VST50F maxillofacial silicone was obtained after addition 1% Al_2o_3-1% Tio_2 hybrid nanoparticles. This study concludes that the addition of various types of fillers with different properties and size scales in proper proportions to maxillofacial silicone elastomer could enhance the mechanical properties. The composite reinforcement with a different filler can positively improve the anti-aging properties of the maxillofacial silicone elastomer as well as the mechanical properties (tear strength, and roughness) to increase the service life of the prostheses.

Conflicts of Interest: The authors have no conflicts of interest.

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