Research Article

Evaluating the effect of barium titanate nanofiller addition on the thermal conductivity and physio-mechanical properties of maxillofacial silicone

Yasir Mohammed Kareem [1], **Thekra Ismael Hamad** [2*], **Matheel AL- Rawas** [3]

1 Kufa University School of Dentistry: Kufa, Najaf, Iraq

2 Department of prosthodontics, College of Dentistry, University of Baghdad, Baghdad, Iraq

3 School of Dental Sciences, Health Campus, Universiti Sains Malaysia, Kubang Kerian, 16150 Kota Bharu, Kelantan, Malaysia.

* Corresponding author: thikra.ismail@codental.uobaghdad.edu.iq

Received date: 10-12-2023
Accepted date: 14-01-2024
Published date: 15-06-2024

https://doi.org/10.26477/jbcd.v36i2.3674

Abstract: Background: Silicone elastomers have been extensively used as the most acceptable material in the manufacturing of maxillofacial and other kinds of prosthetic devices. The durability of maxillofacial prostheses depends on the material chosen, the patient's attitude and feelings regarding the prosthesis, and how they perform for specific needs. Aims: This study aimed to investigate the influence of adding barium titanate ($BaTiO_3$) nanoparticles on the mechanical and physical characteristics of room-temperature-vulcanized (RTV) VerSilTal (VST-50) maxillofacial silicone elastomer, including thermal conductivity, tear strength, and water absorption and solubility. Materials and methods: 0.5 wt% and 0.75 wt% $BaTiO_3$ nanoparticles were added to RTV VST-50 platinum silicone elastomer. Ninety specimens were prepared and divided into three main groups: one control group and two experimental groups (0.5 and 0.75 wt%). The collected data were statistically analyzed by one-way ANOVA and Tukey (HSD) test (significant level at $P \leq 0.05$). The homogeneity and normal distribution of data were assessed by Levene's and Shapiro Wilk's tests, respectively. Result: Both experimental groups showed a remarkable increase in tear strength, thermal conductivity, and water absorption compared with the nonadditive control group. For solubility, the group of 0.5 wt% additive showed an insignificant increase, whereas the group of 0.75 wt% showed a significant increase compared with the control group. Conclusion: The addition of $BaTiO_3$ nanoparticles to RTV VST-50 enhanced the thermal conductivity and tear strength. Water absorption and solubility were also increased, but the values were clinically insignificant. FTIR revealed no chemical interaction between $BaTiO_3$ and silicone. FE-SEM showed the uniform scattering of $BaTiO_3$ inside the silicone matrix.

Keywords: $BaTiO_3$, Maxillofacial silicone, tear strength, thermal conductivity, water absorption and solubility

Introduction:

The face is the first portion of the body to make contact with the outside world, and looking a certain way is now necessary to get a job, appear on television or in magazines, or even get married [(1)]. Especially with the evolution of social media, photography, and technology, interest in appearance, outfit style, and beauty has grown.

Congenital abnormalities, trauma, or tumor surgery may result in facial deformities. Depending on the size or location of the lesion, surgical repair may not be feasible. Moreover, the patient's health or personal preferences may exclude reconstructive surgery. In such cases, prosthetic rehabilitation is advised. Distortions in appearance and function problems from acquired, developmental, and congenital head and neck illnesses may be corrected by a maxillofacial prosthesis that mimics the natural properties of the missing tissues [(2)]. This form of treatment functions as a psychological therapy that facilitates the reintegration of individuals who have experienced social exclusion, physical and psychological debilitation, and humiliation. It also helps restore individuals' self-esteem and confidence [(3)].

A suitable material for the fabrication of a maxillofacial prosthesis must have similar mechanical and physical characteristics to the missing tissues to be replaced and must not deteriorate fast with daily usage [(4, 5)].

Various materials can be developed to construct facial prostheses; among which, silicone elastomer is mainly used. Despite its biocompatibility, low chemical reactivity, simplicity of handling, and optical clarity, the physical and mechanical characteristics of silicone elastomer do not satisfy the ideal requirements, leading to its limited application in extending the clinical life expectancy of prostheses. Strengthening this material might be necessary to address these shortcomings [4, 5]. Among the materials used to create maxillofacial prostheses, silicone is the most effective microorganism retainer. Therefore, the use of water, neutral soap, and chlorhexidine to clean prostheses is advised [6]. Patients must disinfect their maxillofacial prostheses every day to maintain their cleanliness. Different commercially available solutions and others, such as hypochlorite cleansers and neutral soaps, are appropriate for various kinds of elastomer [6, 7]. During their service life, maxillofacial elastomers experience considerable changes in their structure and appearance mostly due to aging induced by exposure to climatic variables, such as sun radiation, temperature, and humidity [8]. Although changes in a polymer's structure impact its mechanical and thermal properties, surface modifications are just as significant. Changes in color and surface, such as hardness, are often the most important reasons for prosthesis replacement because these differences are visible and typically noticed by patients [9].

Approximately 0.20 W/K m is the inherent thermal conductivity of silicone elastomer. Low thermal conductivity is required for prosthetic materials to avoid the cauterization of remaining tissues [10]. Tear strength is the most important characteristic of silicone maxillofacial prostheses. A material can resist rupture when tensile forces are applied to an area of high-stress concentration [11]. This characteristic becomes significant in thin areas, especially around the eyes and nasal prostheses. When adhesives with thin portions are utilized, the prosthesis is likely to get irreversibly damaged after removal [12]. Regarding water absorption, the liquid content of a material has a close relationship with its mechanical characteristics, including size, strength, and appearance [13]. Different polymers may absorb water throughout their service life, resulting in dimension changes that can lead to collapse due to the resulting internal tensions. However, if a material absorbs fluids to the point that it loses its original proportions or becomes soluble, then the function of the prosthesis may be compromised [14].

Many studies discussed the usage of various additives integrated into the silicone matrix to improve its mechanical and physical characteristics [15, 16]. Barium titanate ($BaTiO_3$), a dielectric/ferroelectric semiconductor with perovskite structures, is the most extensively used photocatalyst in environmental applications due to its low cost, chemical stability, and nontoxicity [17]. When incorporated into various substances, including implants, polyvinylsiloxane, and hydroxyapatite, $BaTiO_3$ exhibits antibacterial activity against a wide variety of microorganisms [18]. Other studies proved that $BaTiO_3$ improves the tensile strength, elongation percentage, tear strength, and antibacterial activities of maxillofacial silicone [18, 19].

This study has novelty in investigating the previously unexplored topic of the changes in the thermal conductivity, water absorption, and solubility of $BaTiO_3$ after its addition to maxillofacial silicone. A previous study was conducted in 2023 to explain the effect of $BaTiO_3$ addition to silicone on tear strength, but different percentages were employed [19].

This research was conducted to assess the impact of adding 0.5 and 0.75 wt% $BaTiO_3$ nanofiller on the tear strength, thermal conductivity, and water absorption and solubility of room-temperature-vulcanized (RTV) VST-50 maxillofacial silicone. Whether this addition improves the characteristics of silicone to a level that will meet the required or recommended level for durable prostheses was explored.

Hypothesis of the study: the null hypothesis (H0) suggests that adding $BaTiO_3$ nanoparticles will not affect the physiomechanical properties of maxillofacial silicone. The alternative hypothesis (H1) suggests that adding $BaTiO_3$ nanoparticles will significantly affect the physiomechanical properties of maxillofacial silicone.

Material and Methods

This investigation received approval from the Ethics Committee of the College of Dentistry, University of Baghdad and was carried out within the Department of Prosthodontics. The materials used were $BaTiO_3$ (Sky Spring Nanomaterials, USA) and RTV VST-50 silicone (Factor II Inc., USA). A particle size analyzer was used to prove that the $BaTiO_3$ particles are of a nanoscale.

Pilot study

In our previous study, various weight percentages of $BaTiO_3$ (0.25, 0.5, 0.75, and 1% wt%) were introduced into RTV VST-50 [18]. Results showed that 0.5 and 0.75 wt% produced the best predictable results for thermal conductivity, tear strength, and water absorption and thus were selected for the present work.

Specimen organization

Ninety specimens were prepared and divided equally into three groups (n=30): one control group (A) without $BaTiO_3$ and two experimental groups (B and C) with 0.5 and 0.75 wt% $BaTiO_3$ (n=10).

Design and fabrication of mold

The matrix, bottom, and cover were made from three transparent acrylic sheets with thickness ranging from 2 mm to 6 mm. The matrix sheet was affixed to the bottom sheet with chloroform (adhesive agent) following each test standard to ensure that it remained in place during the pouring of silicone. After the mold was designed with computer software (CorelDraw 2020), it was manufactured using a CNC machine. Nuts and screws were used. For further tightness, G-clamps were also used at the edges [4, 20].

Mixing procedure

VST-50 (RTV) maxillofacial silicone was mixed in a 10:1 ratio as specified by the manufacturer (10 parts base to 1 part catalyst). A vacuum mixer was used to prevent air entrapment.

For the control group, the base and catalyst were weighed on an electronic digital balance and then mixed for 5 minutes. In the experimental groups, the $BaTiO_3$ nanopowder was first weighed and poured into the bowl, followed by the addition of the base portion. The mixture was subsequently mixed for 3 minutes without a vacuum to impede the suction of the nanopowder and then for 7 minutes with air suction. The vacuum pressure was adjusted to −10 bars (−28 inches Hg) with a speed of 140 rpm. The mixture was then allowed to cool for 5 minutes. After being added with the catalyst, the mixture was mixed for 5 minutes [4] [20].

The mixture was poured into the mold, and the cover piece was sealed over it. Screws, nuts, and G-clamps were used to secure the mold. Following the manufacturer's instructions, the mixture was permitted to set for 24 hours at 23 (± 2 °C). In accordance with ISO 23529:2016, the specimens were maintained at 20 °C–25 °C and 50%–10% humidity for 16 hours (Figure 1).

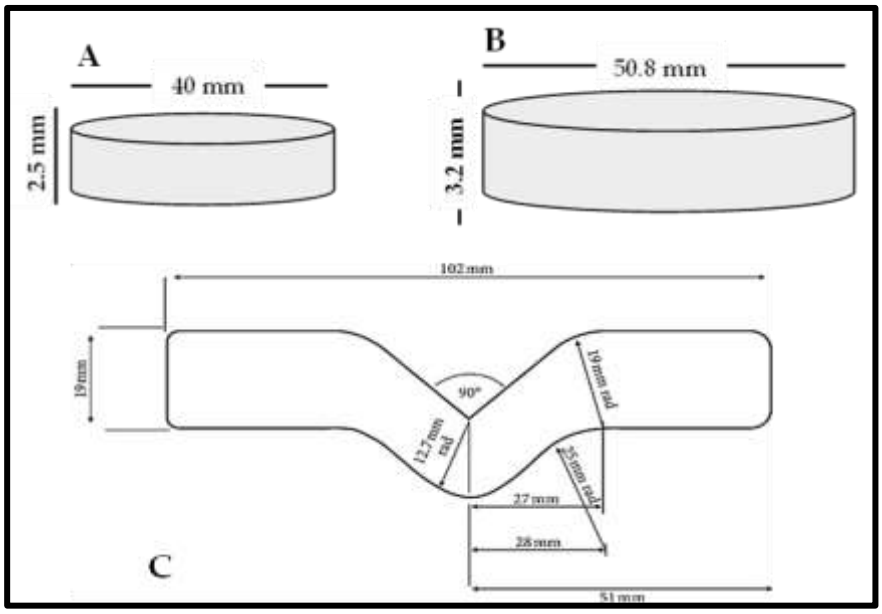

Figure 1: Specimens of the study; A, specimen of thermal conductivity; B, specimen of water absorption and solubility test; c, specimen of tear strength test

Testing procedure

Thermal conductivity test

Thermal conductivity test was performed using the transient plane heat source (TPS) thermal conductivity tester (model: Skz1061C, China) (ISO 22007-2, 2022) [21]. Although TPS requires no specific specimen preparation, the specimen must be smooth and preferably greater than 3 cm in diameter to cover the probe sensor (ISO 22007-2, 2022). The specimen was designed as a disc with a 40 mm diameter and 2.5 mm thickness. This device operates a double helical plane probe etched with alloy sheets. The plane probe, which is both a heat source and a sensor, was placed between two specimens and clamped by a fixture. When measuring the specimen, the power bridge was used to detect the voltage change on the probe and the collected data were sent to the computer software for analysis and processing. Finally, the thermal conductivity was measured in (W/mk), where W represents watts, m is meters, and k is kelvins [21].

Tear strength test

Tear test was carried out following (ISO 34-1, 2022) [22]. Angled specimens with an apex and two ends of 2(±0.2) mm thickness were produced. A digital caliper was used to measure the specimen's thickness at the angled portion (apex) at three locations throughout its width where tearing may occur. The specimen was examined using a computer-controlled universal testing machine (Laryee Technology Co., Ltd., China). For equal transfer of force across the specimen, it must be held precisely between the grips of the universal testing machine. The specimens were held 30(±0.5) mm apart in a universal testing machine. The lowest grip was fixed, and the top grips were mobile. The speed of the testing was 500 mm/min. The maximum force at break was calculated using Equation (1).

$$Ts = f/d, \quad (1)$$

where: Ts represents tear strength, f is the maximum force in Newtons, and d is the thickness of the specimen in millimeters (ISO 34-1, 2022) [22].

Water absorption and solubility tests

The test was performed following ASTM D570 (2005) [11]. Specimens with a diameter of 50.8 mm and a thickness of 3.2 mm were conditioned in a drying oven (Faithful, China) for 24 hours at 50(±3 °C), cooled in a desiccator containing silica gel to absorb the humidity for 3 hours, and instantly weighed on a 0.0001 g accuracy scale digital balance (Denver, Germany). Prolonged immersion was performed to measure the water absorption of the specimens. The conditioned specimens were submerged for 24 hours in distilled water maintained at 23(±1°C). After 24 hours, the specimens were removed from the distilled water, cleaned with a clean, dry cloth, weighed on a 0.0001 g accuracy balance, and immediately returned to the distilled water. These measurements were repeated at the end of 7 days and every 2 weeks until the specimens were deemed saturated and no further increase in weight was observed. This step is crucial to determine the increase in weight. Weight gain was calculated using Equation 2 (ASTM D570, 2005) [11]:

$$\textbf{Increase in weight\%} = \frac{\textit{wet weight} - \textit{conditioned weight}}{\textit{conditioned weight}} \boldsymbol{x}\ \mathbf{100} \qquad (2)$$

After immersion in distilled water, the specimens for the solubility test were reweighed, reconditioned at the same temperature and time as the first drying period, cooled in a desiccator, and immediately reweighed. Solubility was determined by subtracting the reconditioned weight from the conditioned weight, with the difference representing the water-soluble material lost during the immersion test. Equation (3) was used for calculation (ASTM D570, 2005) [11]:

$$\textbf{Solubility\%} = \frac{\textit{conditioned weight} - \textit{reconditioned weight}}{\textit{conditioned weight}} \boldsymbol{x}\ \mathbf{100} \qquad (3)$$

According to (ASTM D570, 2005) [11], the water-absorption value for these materials is the sum of the increase in weight upon immersion and the weight of water-soluble matter.

Fourier transforms infrared spectroscopy (FTIR): FTIR from the IRAffinity-1 laser product (Shimadzu, Japan) was used to determine if the silicone substance and the $BaTiO_3$ nanoparticles reacted chemically. One random specimen from each of groups (A), (B), and (C) was analyzed.

Field emission scanning electron microscope (FE-SEM): a FE-SEM machine (FEI, Netherlands) was used to assess the $BaTiO_3$ nanoparticle diffusion inside the silicone specimen matrix. One random specimen from each of groups (A), (B), and (C) was analyzed.

Statistical analysis: statistical analysis was carried out using statistical analysis software (IBM SPSS Statistics 23). One-way ANOVA and post hoc tests (Tukey HSD) were applied. Levene's and Shapiro–Wilk's test was used to determine the normal distribution of data and the homogeneity of variances, respectively. Probability value of more than 0.05 ($P > 0.05$) was deemed statistically nonsignificant (NS), and $P \leq 0.05$ was statistically significant (S).

Results

Particle size: the effective diameter of $BaTiO_3$ powder after milling was measured by the particle size analyzer device to be 59.4 nm.

FTIR outcome: FTIR analysis demonstrated that $BaTiO_3$ addition did not affect the spectra range of VST-50 silicone (no chemical reaction) (Figure 2).

FE-SEM outcome: as shown in the FE-SEM images (Figure 3), the $BaTiO_3$ nanoparticles were equally dispersed inside the VST-50 silicone matrix and exhibited very slight agglomeration as the filler mass increased. Reduced silicone porosity was also observed in the FE-SEM.

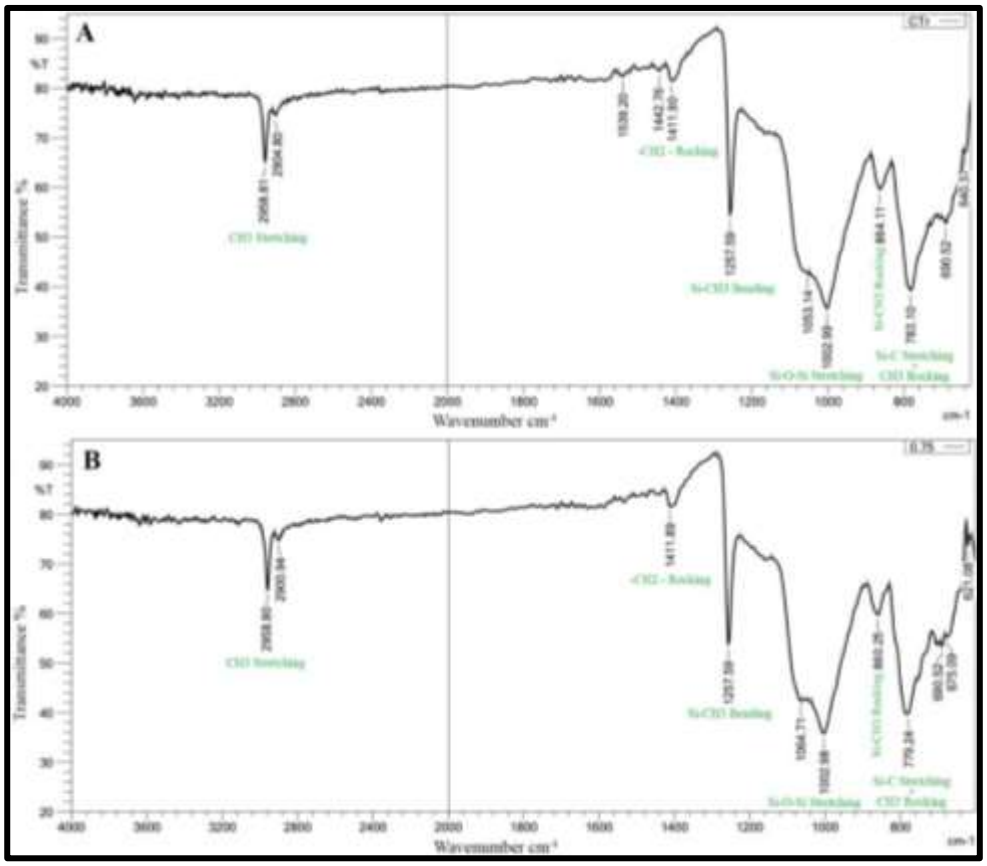

Figure 2: A, FTIR of the control sample; B, FTIR of the sample following incorporation of 0.75wt% $BaTiO_3$, revealed no differences in spectra rang of silicone (no chemical reaction).

Thermal conductivity test:

The mean thermal conductivity of the (0.5% $BaTiO_3$) and (0.75% $BaTiO_3$) groups was greater than that of the control group (0% $BaTiO_3$). One-way ANOVA for the thermal conductivity test revealed a significant variation in mean values across all groups ($P < 0.05$). Tukey HSD test findings showed a significant variation between the control group (0% $BaTiO_3$) and the experimental groups (0.5% $BaTiO_3$ and 0.75% $BaTiO_3$) ($P < 0.05$). The variation between the groups (0.5% $BaTiO_3$ and 0.75% $BaTiO_3$) was also statistically significant ($P < 0.05$). Levene's test confirmed the homogeneous distribution of variances ($P > 0.05$) (Table 1).

Tear strength test:

The mean values of the (0.5% $BaTiO_3$) and (0.75% $BaTiO_3$) groups were both greater than that of the control group (0% $BaTiO_3$). One-way ANOVA for the tear strength test showed a significant variation in mean values across all groups ($P < 0.05$). Tukey HSD test findings showed a significant variation between the control group (0% $BaTiO_3$) and the experimental other groups (0.5% $BaTiO_3$ and 0.75% $BaTiO_3$) ($P < 0.05$). The variation between the 0.5% and 0.75% $BaTiO_3$ groups was also statistically significant ($P < 0.05$). Levene's test confirmed the homogeneous distribution of variances ($P > 0.05$) (Table 2).

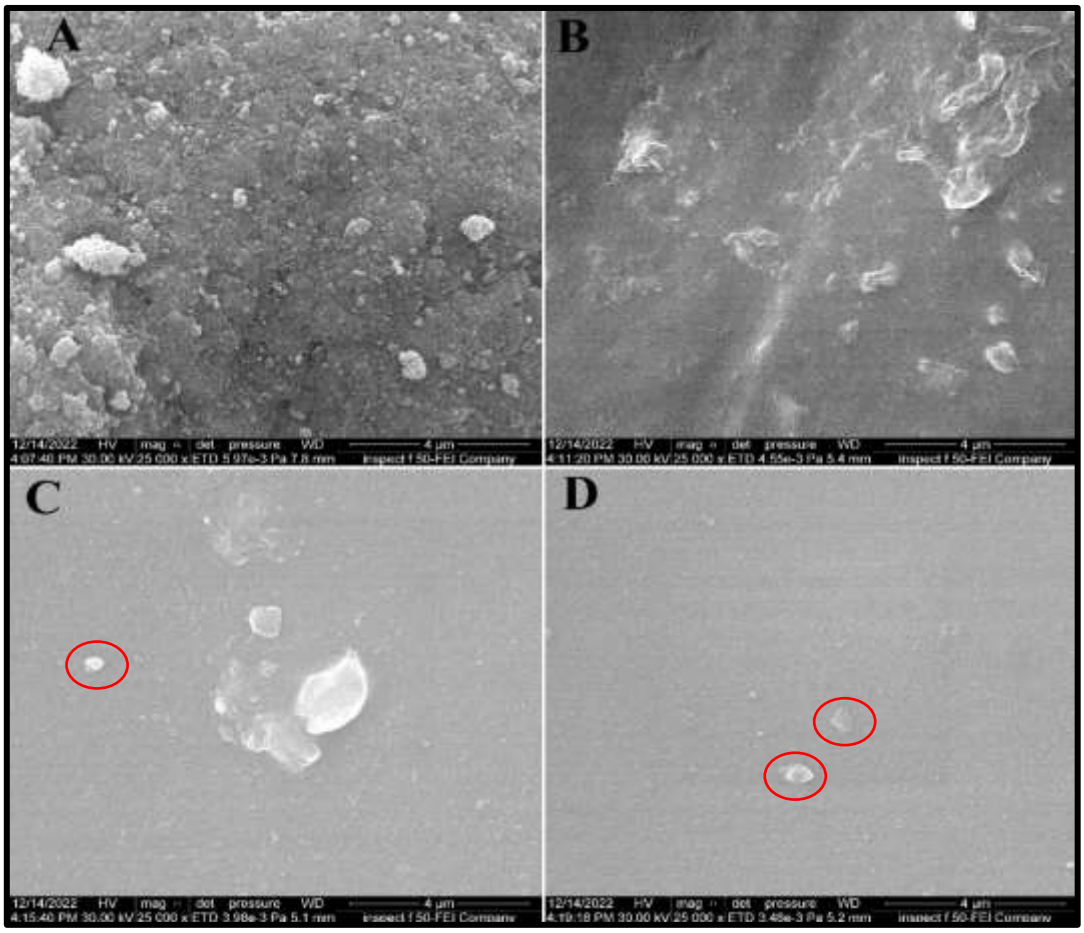

Figure 3: FE-SEM images at 25000 magnification (4 μm) showing the equal scattering of $BaTiO_3$ nanoparticles within the silicone with very minor agglomeration as the filler mass increased: A, $BaTiO_3$; B, control specimen shows porous silicone; C, 0.5 wt% specimen; D, 0.75 wt% specimen. Red circles show $BaTiO_3$ agglomeration.

Table 1: Descriptive statistics, ANOVA, Tukey HSD, and Levene's test of thermal conductivity

Descriptive statistics						ANOVA		Tukey HSD		
Group (n=10)	Mean	±SD	±SE	Min.	Max.	F	*P* value*	Group		*P* value*
0% $BaTiO_3$	0.202	0.009	0.002	0.191	0.217	158.757	<0.001	0% $BaTiO_3$	0.5% $BaTiO_3$	<0.001
0.5% $BaTiO_3$	0.268	0.011	0.003	0.245	0.287				0.75% $BaTiO_3$	<0.001
0.75% $BaTiO_3$	0.306	0.017	0.005	0.284	0.336			0.5% $BaTiO_3$	0.75% $BaTiO_3$	<0.001
Levene's Statistic = 2.723, *P* value* = 0.08										

* Significant level at $P < 0.05$

SD: standard deviation, SE: standard error, BaTiO3: barium titanate

Table 2: Descriptive statistics, ANOVA, Tukey HSD, and Levene's test of tear strength

Groups (n=10)	Descriptive statistics					ANOVA		Tukey HSD		
	Mean	±SD	±SE	Min.	Max.	F	*P* value	Group		*P* value
0% $BaTiO_3$	21.670	1.500	0.474	19.360	23.490	36.697	<0.001	0% $BaTiO_3$	0.5% $BaTiO_3$	<0.001
0.5% $BaTiO_3$	23.707	0.855	0.270	22.540	25.150				0.75% $BaTiO_3$	<0.001
0.75% $BaTiO_3$	26.922	1.657	0.524	24.540	29.520			0.5% $BaTiO_3$	0.75% $BaTiO_3$	<0.001
Levene's Statistic = 2.553, *P* value = 0.09										

* Significant level at $P < 0.05$

SD: standard deviation, SE: standard error, BaTiO3: barium titanate

Water absorption and solubility test

Water absorption: the mean values of the (0.5% $BaTiO_3$) and (0.75% $BaTiO_3$) groups were both greater than that of the control group (0% $BaTiO_3$). One-way ANOVA for the water absorption test showed a significant variation in mean values across all groups ($P < 0.05$). Tukey HSD test findings revealed a significant variation between the control group (0% $BaTiO_3$) and the 0.5% $BaTiO_3$ group ($P \leq 0.05$). The variation between the control (0% $BaTiO_3$) and 0.75% $BaTiO_3$ groups and between the experimental groups (0.5% $BaTiO_3$ and 0.75% $BaTiO_3$) was significant ($P < 0.05$). Levene's test confirmed the homogeneous distribution of variances ($P > 0.05$) (Table 3).

Water solubility: the mean values of the (0.5% $BaTiO_3$) and (0.75% $BaTiO_3$) groups were both greater than that of the control group (0% $BaTiO_3$). One-way ANOVA for the solubility test showed a nonsignificant variation in mean values across all groups ($P > 0.05$). Tukey HSD test findings revealed significant variation between the control group (0% $BaTiO_3$) and the 0.75% $BaTiO_3$ group ($P \leq 0.05$). The difference between the control (0% $BaTiO_3$) and 0.5% $BaTiO_3$ groups and between the experimental groups (0.5% $BaTiO_3$ and 0.75% $BaTiO_3$) was nonsignificant ($P > 0.05$). Levene's test confirmed the homogeneity of variances ($P > 0.05$) (Table 4).

Table 3: Descriptive statistics, ANOVA, Tukey HSD, and Levene's test of water absorption

Water absorption test	Descriptive statistics					ANOVA		Tukey HSD		
Groups (n=10)	Mean	±SD	±SE	Min.	Max.	F	Sig.	Group		*P* value
0% $BaTiO_3$	0.101	0.014	0.004	0.080	0.128	31.876	<0.001	0% $BaTiO_3$	0.5% $BaTiO_3$	0.01 **S**
0.5% $BaTiO_3$	0.124	0.016	0.005	0.099	0.149				0.75% $BaTiO_3$	<0.001
0.75% $BaTiO_3$	0.160	0.018	0.005	0.120	0.182			0.5% $BaTiO_3$	0.75% $BaTiO_3$	<0.001
Levene's Statistic = 0.199, *P* value = 0.821										

* Significant level at $P < 0.05$

SD: standard deviation, SE: standard error, $BaTiO_3$: barium titanate

Table 4: Descriptive statistics, ANOVA, Tukey HSD, and Levene's test of water solubility

Water solubility test			Descriptive statistics			ANOVA		Tukey HSD		
Groups (n=10)	Mean	±SD	±SE	Min.	Max.	F	*P* value	Group		*P* value
0% $BaTiO_3$	0.020	0.009	0.002	0.010	0.037	31.876	0.05	0% $BaTiO_3$	0.5% $BaTiO_3$	0.78
0.5% $BaTiO_3$	0.023	0.004	0.001	0.018	0.031				0.75% $BaTiO_3$	0.05
0.75% $BaTiO_3$	0.029	0.009	0.003	0.013	0.049			0.5% $BaTiO_3$	0.75% $BaTiO_3$	0.18
Levene's Statistic of solubility = 1.500, *P* value = 0.241										

* Significant level at $P < 0.05$

SD: standard deviation, SE: standard error, BaTiO3: barium titanate

Discussion:

Commercially available maxillofacial silicones differ considerably from each other because of their various formulations and ingredients. Although manufacturers always provide records of the mechanical properties of silicone materials lacking any additives such as coloring agents or reinforcing fillers, these records are not an accurate representation of silicone elastomers used in regular clinical practice (Factor II, 2013) [23].

Thermal conductivity refers to the capacity of a material sample to predict the rate of heat transfer across a designated cross-sectional area over a specific period [24]. Several efforts have concentrated on distributing 1D or 2D micro- or nanostructure fillers into polymers to enhance the heat transfer through these materials. A composite's thermal conductivity is affected by the conductivities of the matrix and filler and the filler's size, shape, and concentration [25].

A material's structure influences the way heat is transported and therefore how well this material conducts heat. Free electrons are used to carry heat in metals; phonons, which are lattice waves generated by the vibrational energy of atoms, are used to conduct heat in nonmetallic materials such as polymers [24, 26]. Given that phonons play a crucial factor in measuring heat conductivity via their mean free pathways, the interfacial physical contact between polymer and filler is crucial for two-phase systems such as polymer/filler composites [24, 27]. The compact structure of composites may be used to explain this phenomenon. As the particles are added to the matrix, they occupy the gaps and decrease the free volume (air-filled voids), creating composites with a compact structure and better heat conductivity than pure polymers [25].

The increased thermal conductivity in this study was expected because $BaTiO_3$ is a semiconductor material with a cure temperature of approximately 120 °C [28] and a thermal conductivity of (2.85±0.04 W/m.k) [29], which is much higher than that of silicone (0.21 W/m.k) [3]. The FE-SEM findings also demonstrated that together with the high thermal conductivity of $BaTiO_3$ nanoparticles, the homogeneous dispersion of $BaTiO_3$ nanoparticles within the silicone matrix may explain the high thermal conductivity of the specimens. Furthermore, the extremely considerable increase in thermal conductivity rates may be caused by the particles gradually interacting with one another to form a network-like configuration known as heat conductive pathway.

This pathway allows heat to transfer from one side of the specimen to another and bridge the insulating effect of the polymer. As a consequence, the polymer shows high thermal conductivity [31]. This result agreed with findings of Al-Naser and Abdul-Ameer, 2022 [24], who found an increase in the thermal conductivity of VST-50HD after adding yttrium oxide nanoparticles (Y_2O_3), and those of Abdulmajeed and Abdulbaqi, 2023 [32], who found an increase in the thermal conductivity of polyethylmethacrylate after

adding calcium carbonate ($CaCO_3$). In addition, Kamil and Al-Judy, 2018 [33] verified that the addition of silicon carbide (SiC) nanoparticles into heat-cured acrylic denture base resin increased the thermal conductivity property, and this effect was concentration dependent.

Tear strength refers to the material's resistance to tearing force and deformation and demonstrates how well the material maintains its integrity. Tear strength is very important in facial prostheses, especially at the thin margins where the prostheses meet the skin [4, 24]. Environmental conditions, cleaning products, and physical cleaning may all hasten these impacts [34].

Physically, certain polymer chains may be trapped by nanoparticles by creating 3D networks inside the matrix of the polymer, producing filler meshes within the polymer matrix. Polymer chains cannot move opposite to the nanoparticles or against one another as a result of the interaction between the nanoparticles and the polymer matrix. In turn, this phenomenon leads to an increase in density and tear strength [4, 24]. Rubber materials also could disperse strain energy at the crack's propagation point.

When the split spreads, the nanoparticles may disperse their energy and maximize the material's resistance to tearing [4]. These results agreed with previous studies (Fatihallah and Alsamaraay, 2017; Al-Obaidi and Ali, 2019; Tukmachi et al., 2021) [3, 35, 36], which found improvement in tear strength. However, these findings disagreed with those of Nobrega et al., 2016 [37], who revealed inconsistent outcomes of increases and decreases in tear strength values with the addition of ZnO, TiO_2, and $BaSO_4$ nanoparticles to silicone MDX4-4210. Furthermore, Chowdhary (2020) [38] observed that the silicone's tear strength values remained the same after the addition of silver nanoparticles. The use of different silicones and nanoparticles at various ratios may be the cause of these variations.

Water absorption and solubility: water absorption is a critical physical characteristic of maxillofacial prostheses exposed to saliva, water, or other fluids used by the patient for cleaning. Every liquid that is absorbed by the material can alter the latter’s mechanical properties, appearance, and dimensions ASTM D570 (2005). An ideal facial prosthesis must have minimum levels of absorbance and solubility because these properties are related to surface degradation and elasticity loss, which could cause increased stiffness, discoloration, and microbial infection. When silicone prostheses absorb moisture, the moisture becomes trapped within the polymer chains and causes them to break, leading to a slight expansion of the polymerized material that changes its mechanical qualities such as hardness [9].

Water absorption results revealed a significant increase in absorbed water for the experimental groups (0.5 and 0.75wt% $BaTiO_3$) compared with the control specimens. This phenomenon may be due to the dry nature of nanoparticles, causing the silicone to absorb a large amount of water [39]. This characteristic is probably connected to the kind of filler and the strength of the bond between the filler and the silicone rubber. Braden and Wright asserted that the kind of filler may have an impact on the rubber's ability to absorb water [40]. Moreover, prolonged storage of silicones may result in water absorption due to the load component in the formulation and the silicone polymers' reduced adhesion degree [41].

This phenomenon may also be attributed to the fact that VST-50 silicone is an additional kind of silicone and not a condensation silicone. An addition silicone cures without producing any byproducts, and a condensation-cured silicone cures with byproducts that eventually depart from the polymer's structure, creating a structure that is more porous than that of addition silicones [42]. Moreover, silicone rubbers can withstand prolonged immersion in hot or cold water with absorption rates of less than 1% and exhibit essentially no change on their mechanical and electrical properties [43].

These results agreed with the findings of Canay et al., 1999 and Parker et al., 1999 [44, 45] who discovered that silicone-type materials absorbed less water than plasticized acrylics due to the former’s highly hydrophobic nature; those of Salih et al., 2018 [46], who looked into the effects of adding synthetic and natural powders and fibers to a mixture of VST-50 silicone and polymethyl methacrylate; and those of dos

Santos et al., 2012 [47], who examined the addition of pigments and opacifiers to the MDX10 silicone, which is matched to VST-50 in chemistry and flexibility [48].

For solubility, ANOVA results revealed a nonsignificant variation in mean values across all groups. Significant variation ($P \leq 0.05$) was only observed between the (0.75wt% $BaTiO_3$) group and the control group. Given that $BaTiO_3$ is insoluble in water [49], the low solubility may be due to the slow release of formaldehyde, a special characteristic of polymerized elastomers at room temperature [40].

The water solubility of silicones cross-linked at room temperature is assumed to be caused by the loss of alcohol produced as a chemical by-product and the extraction of the metallic salt catalyst, which is left unaltered in the process [40]. Given that silicones lack water-soluble components such as plasticizers, which allow for absorption and solubility, they have far lower absorption and solubility than acrylics [50]. The findings supported those of Hulterström et al., 2008 [42], who discovered that certain specimens of addition silicone lost weight upon reconditioning; and those of dos Santos et al., 2012 [47], who looked at the effects of adding colors and opacifiers to MDX10 silicone.

Conclusion:

The addition of $BaTiO_3$ nanopowder significantly enhanced the tear strength and thermal conductivity of RTV VST-50 silicone elastomer, and this effect was directly proportional to the added $BaTiO_3$ concentration. Water absorption and solubility increased after the incorporation of $BaTiO_3$ into RTV VST-50 silicone; however, clinically, the values are insignificant. FTIR showed no chemical reaction, and FE-SEM revealed decreased porosity in the silicone matrix. Further study must explore the antifungal activity of $BaTiO_3$, artificial aging, and $BaTiO_3$ addition to pigmented silicone.

Conflict of interest:

All authors hereby certify that they have no conflicts of Interest.

Author contributions:

All authors contributed to study conception and design, data collection, methodology, statistical analysis, and interpretation of results. Original draft manuscript preparation. All authors reviewed the results and approved the final version of the manuscript to be published.

Acknowledgement and funding:

No grant or financial support was received from any governmental or private sector for this study

References:

1. Padmaja S. An insight into the future beckons of maxillofacial prosthodontics; Anaplastology. J Dent Res rev 2015; 2(2):91-96. https://doi.org/10.4103/2348-2915.161213

2. Cevik P, Eraslan O. Effects of the addition of titanium dioxide and silaned silica nanoparticles on the mechanical properties of maxillofacial silicones. J Prosth 2017; 26(7):611-5. https://doi.org/10.1111/jopr.12438

3. Fatihallah AA, Alsamaraay ME. Effect of polyamide (Nylon 6) micro-particles incorporation into RTV maxillofacial silicone elastomer on tear and tensile strength. J Bagh Coll Dent 2017; 29(4):7-12. https://doi.org/10.12816/0042985

4. Ahmed AS, Ali MM. Effect of Strontium Titanate Nano Powder Addition on Some Mechanical Properties of Room Temperature Vulcanized Maxillofacial Silicone. J Res Med Dent Sci 2021; 9(12):59-65.

5. Al-Hiloh, SA, Ismail IJ. A study the effect of addition of silanized zirconium oxide nanoparticles on some properties of high-impact heat-cured acrylic resin. J Bagh Coll Dent 2016; 325(3500):1-7. https://doi.org/10.12816/0028208

6. Goiato MC, Zucolotti BC, Mancuso DN, dos Santos DM, Pellizzer EP, Verri FR. Care and cleaning of maxillofacial prostheses. J. Arch. Craniofac. Surg 2010; 21(4):1270-3. https://doi.org/10.1097/SCS.0b013e3181e1b431

7. Hatamleh MM, Polyzois GL, Silikas N, Watts DC. Effect of extraoral aging conditions on mechanical properties of maxillofacial silicone elastomer. J. Prosthodont 2011; 20(6):439-46. https://doi.org/10.1111/j.1532-849X.2011.00736.x

8. Sampers J. Importance of weathering factors other than UV radiation and temperature in outdoor exposure. Polym. Degrad. Stab 2002; 76(3):455-65. https://doi.org/10.1016/S0141-3910(02)00049-6

9. Guiotti AM, Goiato MC, dos Santos DM. Evaluation of the Shore A hardness of silicone for facial prosthesis as to the effect of storage period and chemical disinfection. J. Craniofac. Surg 2010; 21(2):323-7. https://doi.org/10.1097/SCS.0b013e3181cf5fa4

10. Liu Q, Shao LQ, Xiang HF, Zhen D, Zhao N, Yang SG, et al., Biomechanical characterization of a low-density silicone elastomer filled with hollow microspheres for maxillofacial prostheses. J. Biomater. Sci. Polym. Ed 2013; 24(11):1378-90. https://doi.org/10.1080/09205063.2012.762292

11. Anusavice, K. Philips' science of dental materials, 12th ed. Missouri: 2012 Saunders Co.

12. Mitra A, Choudhary S, Garg H, Jagadeesh HG. Maxillofacial prosthetic materials-an inclination towards silicones. J Clin Diagn Res 2014; 8(12):ZE08-13. https://doi.org/10.7860/JCDR/2014/9229.5244

13. ASTM D 570. Standard Test Method for Water Absorption of Plastic. Annual Book of ASTM Standard D 570-98, 2015; 08.81:1-3.

14. Pfeiffer P, Rosenbauer EU. Residual methyl methacrylate monomer, water sorption, and water solubility of hypoallergenic denture base materials. J. Prosthet. Dent 2004; 92(1):72-8. https://doi.org/10.1016/j.prosdent.2004.04.003

15. Fouad M, Moudhaffer M. Effect of disinfection on some properties of heat-vulcanized maxillofacial silicone elastomer reinforced by nano silicone dioxide. J Bagh Coll Dent 2016; 325(3955):1-6. https://doi.org/10.12816/0033205

16. AbdulKareem AA, and Hamad TI. The effects of nano alumina on mechanical properties of room temperature vulcanized maxillofacial silicone (pilot study). J Bagh Coll Dent 2019; 31(4);59-62. https://doi.org/10.26477/jbcd.v31i4.2722

17. Jiang B, Iocozzia J, Zhao L, Zhang H, Harn YW, Chen Y, et al., Barium titanate at the nanoscale: controlled synthesis and dielectric and ferroelectric properties. Chem Soc Rev 2019; 48(4):1194-228. https://doi.org/10.1039/C8CS00583D

18. Kareem YM, Hamad TI. Assessment of the antibacterial effect of Barium Titanate nanoparticles against Staphylococcus epidermidis adhesion after addition to maxillofacial silicone. F1000research 2023; 12(385):385. https://doi.org/10.12688/f1000research.132727.2

19. Kumail AF, Hamad TI. Evaluation of some Mechanical Properties of Room Temperature Maxillofacial Silicone after the addition of Nano Barium Titanate. Revis Bionatura 2023; 8(3)35. http://dx.doi.org/10.21931/RB/CSS/2023.08.03.35

20. Alanssari BF, Khalaf BS. Effect of Addition of Composite Polyamide Micro Particles and Silicone Dioxide NanoParticle on Some Mechanical Properties of Room Temperature Vulcanized Maxillofacial Silicone Elastomer Before and after Artificial Aging. Indian J. Forensic Med. Toxicol 2020; 14(1):1013-9 https://doi.org/10.37506/ijfmt.v14i1.187

21. ISO 22007-2. Plastics - Determination of thermal conductivity and thermal diffusivity - Part 2: Transient plane heat source (Hot disk) method, 2022 Jun; Third Edition.

22. ISO 34-1. Rubber, vulcanized or thermoplastic - Determination of tear strength -- Part 1: Trouser, angle and crescent test pieces. 2022 Jun; Fifth Edition.

23. Factor II. (2013). Product information VST Platinum Silicone Elastomer [Online]. Available: https://www.factor2.com [Accessed 20 August 2018].

24. Zainab H Al-Naser, Faiza M Abdul-Ameer. Effect of Addition of the Intrinsic Pigment on the Some Physical and Mechanical Properties of Modified Silicone Elastomer with Nano Yttrium Oxide, J Res Med Dent Sci 2022; 10(3):180-187.

25. Agarwal S, Saxena NS, Kumar V. Study on effective thermal conductivity of zinc sulphide/poly (methyl methacrylate) nanocomposites. Appl. Nanosci 2015; 5(6):697-702. https://doi.org/10.1007/s13204-014-0365-7

26. Li S, Yang X, Hou J, Du W. A review on thermal conductivity of magnesium and its alloys. J. Magnes. Alloy 2020; 8(1):78-90. https://doi.org/10.1016/j.jma.2019.08.002

27. Pásztory Z. An overview of factors influencing thermal conductivity of building insulation materials. J. Build. Eng 2021; 44:102604. https://doi.org/10.1016/j.jobe.2021.102604

28. Xing J, Radovic M, Muliana A. Thermal properties of BaTiO3/Ag composites at different temperatures. Compos. B. Eng 2016; 90:287-301. https://doi.org/10.1016/j.compositesb.2015.12.014

29. He Y. Heat capacity, thermal conductivity, and thermal expansion of barium titanate-based ceramics. Thermochim. Acta 2004; 419(1-2):135-41. https://doi.org/10.1016/j.tca.2004.02.008

30. Borik MA, Volkova TY, Kulebyakin AV, Kuritsyna IE, Lomonova EE, Myzina VA, et al. Thermal conductivity of cubic ZrO 2 single crystals stabilized with yttrium oxide. Phys. Solid State 2020; 62(1):235-9. https://doi.org/10.1134/S1063783420010072

31. Yu Z, Wang X, Bian H, Jiao L, Wu W, Dai H. Enhancement of the heat conduction performance of boron nitride/cellulosic fibre insulating composites. PLoS One 2018; 13(7): e0200842. https://doi.org/10.1371/journal.pone.0200842

32. Abdulmajeed SK, Abdulbaqi HJ. Evaluation of Some Properties of Heat Cured Soft Denture Liner Reinforced with Calcium Carbonate Nano-Particles. J Res Med Dent Sci. 2023 Jan;11(1):208-214.

33. Kamil AS, Al-Judy HJ. Effect of addition of silanized silicon carbide nanoparticles on some physical properties of heat cured acrylic denture base material. J Res Med Dent Sci 2018; 6(6):86-95.

34. de Azevedo MN, Marques NT, Fonseca MF, Schuch LF, de Arruda JA, Santos VR, et al. Disinfectant effects of Brazilian green propolis alcohol solutions on the Staphylococcus aureus biofilm of maxillofacial prosthesis polymers. J. Prosthet. Dent 2022; 28(6):1405-1411. https://doi.org/10.1016/j.prosdent.2021.03.025

35. Tukmachi MS, Safi IN, Ali MM. Evaluation of mechanical properties and cytotoxicity of maxillofacial silicone material after incorporation of zirconia nanopowder. Mater. Today: Proc 2021; 42:2209-17. https://doi.org/10.1016/j.matpr.2020.12.306

36. Al-Obaidi KA, Ali MM. The Influence of Halloysite Nanotube Addition on Some Properties of Room Temperature Vulcanized Maxillofacial Silicone before and after Simulated Aging. Indian J Public Health Res Dev 2019; 10(10): 1770-1775. https://doi.org/10.5958/0976-5506.2019.03100.0

37. Nobrega AS, Andreotti AM, Moreno A, Sinhoreti MA, Dos Santos DM, Goiato MC. Influence of adding nanoparticles on the hardness, tear strength, and permanent deformation of facial silicone subjected to accelerated aging. J. Prosthet. Dent 2016; 116(4):623-9. https://doi.org/10.1016/j.prosdent.2016.03.004

38. Chowdhary R. Effect of adding silver nanoparticle on physical and mechanical properties of maxillofacial silicone elastomer material-an in-vitro study. J. Prosthodont. Res 2020; 64(4):431-5. https://doi.org/10.1016/j.jpor.2019.12.001

39. Begum Z, Kola MZ, Joshi P. Analysis of the properties of commercially available silicone elastomers for maxillofacial prostheses. Int. j. contemp. dent. 2011; 2(4):1-5.

40. Braden M, Wright PS. Water absorption and water solubility of soft lining materials for acrylic dentures. J. Dent. Res 1983; 62(6):764-8. https://doi.org/10.1177/00220345830620061601

41. Qudah S, Huggett R, Harrison A. The effect of thermocycling on the hardness of soft lining materials. Quintessence Int 1991; 22(7):575-80.

42. Hulterström AK, Berglund A, Ruyter IE. Wettability, water sorption and water solubility of seven silicone elastomers used for maxillofacial prostheses. J. Mater. Sci.: Mater. Med 2008; 19(1):225-31. https://doi.org/10.1007/s10856-006-0027-8

43. Industrialrubbergoods.com. (2021). Si Rubber, Silicone Rubber Properties and Disadvantages. [online] Available at: http://www.industrialrubbergoods.com/silicone-rubber.html [Accessed 14 March 2023].

44. Canay Ş, Hersek N, Tulunoğlu I, Uzun G. Evaluation of colour and hardness changes of soft lining materials in food colorant solutions. J. Oral Rehabil 1999; 26(10):821-9. https://doi.org/10.1046/j.1365-2842.1999.00477.x

45. Parker S, Martin D, Braden M. Soft acrylic resin materials containing a polymerisable plasticiser II: Water absorption characteristics. Biomaterials 1999; 20(1):55-60. https://doi.org/10.1016/S0142-9612(98)00134-3

46. Salih SI, Oleiwi JK, Ali HM. Study Some Physical Properties of Polymeric Blends (SR/PMMA). IQJMME 2018; 18(4):21-40. https://doi.org/10.32852/iqjfmme.v18i4.235

47. dos Santos DM, Goiato MC, Moreno A, Pesqueira AA, de Carvalho Dekon SF, Guiotti AM. Effect of addition of pigments and opacifier on the hardness, absorption, solubility and surface degradation of facial silicone after artificial ageing. Polym. Degrad. Stab 2012; 97(8):1249-53. https://doi.org/10.1016/j.polymdegradstab.2012.05.033

48. Chi YH. Effect of silica filler on the mechanical properties of silicone maxillofacial prosthesis. MSc Thesis, Indiana University School of Dentistry, Indianapolis (MI). 2014.

49. Tripathy SS, Raichur AM. Dissolution properties of BaTiO3 nanoparticles in aqueous suspensions. J. Exp. Nanosci 2011; 6(2):127-37. https://doi.org/10.1080/17458080.2010.483695

50. Lassila LV, Mutluay MM, Tezvergil-Mutluay A, Vallittu PK. Bond strength of soft liners to fiber-reinforced denture-base resin. J Prosthodont 2010; 19(8):620-4. https://doi.org/10.1111/j.1532-849X.2010.00642.x

العنوان: تقييم إضافة حشوات النانو تيتانات الباريوم على التوصيل الحراري وبعض الخواص الفيزيائية الميكانيكية لسيليكون الوجه والفكين

ياسر محمد كريم، ذكرى إسماعيل حمد، مثيل الرواس

المستخلص:

: في حين أن مطاط السيليكون له تاريخ طويل من الاستخدام على نطاق واسع في تصنيع أجهزة الوجه والفكين وأنواع أخرى من الأجهزة التعويضية، إلا أنها ليست مثالية في جميع النواحي. تعتمد متانة الأطراف الاصطناعية للوجه والفكين على المادة المختارة، وموقف المريض ومشاعره تجاه الطرف الاصطناعي، وقد ترتبط أيضًا بشكل مباشر بمدى جودة أداء الطرف الاصطناعي فيما يتعلق بأهدافه. هدفت هذه الدراسة إلى دراسة تأثير إضافة جزيئات تيتانات الباريوم النانوية بنسبة الوزن المناسبة على الخصائص الميكانيكية والفيزيائية لمطاط السيليكون للوجه والفكين RTV VST-50، بما في ذلك التوصيل الحراري، وقوة التمزق، وامتصاص الماء والذوبان. تم إدخال نسبتين من الوزن (0.5٪ بالوزن و0.75٪ بالوزن) من جزيئات تيتانات الباريوم النانوية إلى مطاط السيليكون البلاتيني RTV VST-50. تم إنتاج 90 عينة قسمت إلى ثلاث مجموعات: مجموعة ضابطة ومجموعتين تجريبيتين. تم تحليل البيانات التي تم جمعها إحصائيا باستخدام تحليل التباين أحادي الاتجاه (ANOVA) واختبار توكي للفرق الهام (HSD) (مستوى كبير عند $p \geq 0.05$). يتم استخدام اختبارات ليفين وشابيرو ويلك لتقييم تجانس البيانات وتوزيعها الطبيعي، على التوالي. أظهرت كلا المجموعتين التجريبيتين (0.5% بالوزن و0.75% بالوزن) زيادة كبيرة للغاية في قوة التمزق والتوصيل الحراري بالمقارنة مع مجموعة التحكم. أظهرت مجموعة 0.5% بالوزن من امتصاص الماء زيادة معنوية، بينما أظهرت المجموعة 0.75% بالوزن زيادة معنوية للغاية. بالنسبة لاختبار الذوبان أظهرت المجموعة 0.5% بالوزن زيادة غير معنوية، بينما أظهرت المجموعة 0.75% بالوزن زيادة معنوية في الذوبان بالمقارنة مع مجموعة السيطرة. أظهرت إضافة تيتانات الباريوم ($BaTiO_3$) إلى RTV VST-50 تحسينات في التوصيل الحراري واختبار قوة التمزق. تم زيادة امتصاص الماء والذوبان. ومع ذلك، سريريا، القيم ضئيلة. لم يكشف FTIR عن أي تفاعل كيميائي بين $BaTiO_3$ والسيليكون. أظهر FE-SEM تشتت جيد لـ $BaTiO_3$ داخل مصفوفة السيليكون..