

# Evaluation the Effect of Nano Yttrium Oxide Addition on the Mechanical Properties of Room Temperature-Vulcanized Maxillofacial Silicone Elastomers

Yasir N. Al-Mohammad

*MSc. Dept. of Prosthodontics, College of Dentistry, University of Baghdad, Baghdad-Babulmoadam, Iraq*

## Abstract

**Objective:** This study aims to investigate the effects of yttrium oxide ( $Y_2O_3$ ) nanopowder inclusion on the mechanical properties, including tear strength, tensile strength, elongation percentage, hardness, and surface roughness, of room temperature-vulcanized maxillofacial silicone elastomers.

**Materials and Method:**  $Y_2O_3$  nanoparticles (30–45 nm) were added to VST50F platinum silicone elastomers in two weight percentages (1 and 1.5 wt%) as tested by the pilot study that showed superior results. A total of 120 specimens were qualified and divided into the control group and experimental groups (1 and 1.5 wt%  $Y_2O_3$ ). Each group was subdivided into four identical subgroups in accordance with intentionally performed tests (tear strength, tensile strength and elongation percentage, shore A hardness, and surface roughness). For each subgroup, 10 specimens were used for each test. Data were statistically analyzed with significance level considered at  $p < 0.05$ . Scanning electron microscopy (SEM) and Fourier transform infrared spectroscopy (FTIR) were also conducted.

**Results and Discussion:** SEM showed that NPs were distributed well within the silicon matrix. FTIR spectra proved no chemical reaction occurred between the  $Y_2O_3$  NPs and VST50F silicone. Tear strength and hardness values significantly increased in the experimental groups compared with the control group. Tensile strength and surface roughness values increased non significantly. Elongation percentage values decreased non significantly.

**Conclusion:** Incorporating  $Y_2O_3$  NPs into VST50F maxillofacial silicone improved the tear strength with slight increase in tensile strength. Hardness and surface roughness increased but within accepted clinical levels. Elongation percentage slightly decreased.

**Keywords:** *maxillofacial silicone,  $Y_2O_3$ , nanoparticles, mechanical properties.*

## Introduction

Prosthetic rehabilitation may become unavoidable for multiple reasons because of the extent or site of facial defect following congenital anomaly, injury, or after

excision of tumors<sup>1</sup>. Materials such as ivory or metals were used in the past, but polymers such as silicone elastomers have recently become the most preferred for the construction of maxillofacial prostheses because of their chemical dormancy, endurance, easy usage, and *biocompatibility*<sup>2</sup>. However, given their anticipated half-life and deterioration of mechanical properties and color stability, maxillofacial prostheses composed of silicone elastomers require refabrication<sup>3</sup>. Factors that influence the mechanical proprietary of silicone elastomers are the atomic density of polymer chains, cross-linking closeness, and presence of fillers<sup>4</sup>. Throughout the evolution of the nanoparticle (NP) industry, NPs have

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### Corresponding author

**Faiza M. Abdul-Ameer,**

MSc. Assistant Professor, Dept. of prosthodontics, college of Dentistry, University of Baghdad, Baghdad-Babulmoadam, Iraq;

dr.fmha@codental.uobaghdad.edu.iq

009647901963234

merged into the polymer matrix to equip a modified polymer characterized by an augmented properties gained from the reinforcing effect of the nano-oxides <sup>5</sup>.

Considerable studies were operated to overcome the mechanical weaknesses of materials, such as reinforcing fillers. A previous study found that adding TiO<sub>2</sub>, ZnO, and CeO<sub>2</sub> as nanofillers to A-2186 silicone in two weight percentages (2.0% and 2.5%) improves the overall mechanical properties (tear strength, tensile strength, and elongation percentage) of the material<sup>6</sup>. Another study analyzed the influence of adding (nano ZnO, BaSO<sub>4</sub>, and TiO<sub>2</sub> at 1 and 2 wt%) on the tear strength, hardness, and permanent deformation of silicone and recommended the use of ZnO NPs to reinforce (Silastic MDX4-4210) silicone <sup>7</sup>. In general, a powerful interaction occurs at the interface between the organic polymeric matrix and the NPs and produces a reinforcing effect<sup>8</sup>. In the present study, Y<sub>2</sub>O<sub>3</sub> nanofillers were added to VST50F RTV maxillofacial silicone elastomer to enhance its mechanical properties.

## Materials and Method

Y<sub>2</sub>O<sub>3</sub> nanopowder (US Research Nanomaterials, Inc., USA) was added to VST50F room temperature-vulcanized maxillofacial silicone elastomers (Factor II, Inc., Lakeside, AZ, USA) to investigate its effect on some mechanical characteristics.

**Pilot study:** The best weight percentage of nano Y<sub>2</sub>O<sub>3</sub> to improve the tear strength with minimal effect on the hardness of the silicone elastomer was selected. The most suitable weight percentages were 1 and 1.5 wt%.

**Study grouping:** A total of 120 specimens were fabricated and divided into the control group (silicone without nano Y<sub>2</sub>O<sub>3</sub> addition referred to as group A) and experimental groups (with 1% Y<sub>2</sub>O<sub>3</sub> addition referred to as group B and with 1.5% Y<sub>2</sub>O<sub>3</sub> addition referred to as group C). Each group was subdivided into four identical subgroups in accordance with intentionally performed tests.

**Mold making:** An autoCAD (Computer Aided Design) software was used to design the dimensions of specimens, and then a Computer Numerical Control machine (JL-1612, Jinan Link Manufacture and Trading Co., Ltd., China) was used to obtain the matrix compartment of the mold where the material will be poured<sup>9</sup>.

**Mixing base, catalyst, and nano Y<sub>2</sub>O<sub>3</sub>:** Y<sub>2</sub>O<sub>3</sub> nanopowder was measured using a digital electronic balance with 0.000 accuracy (China) followed by adding the intended amount of silicone base to avoid the scattering of volatile nanopowder and subsequent weight measurement change <sup>10</sup>. The silicone base was mixed with the nanopowder by using a vacuum mixer (Multivac 3, Degussa, Germany) for 10 min at 360 rpm to form the modified base. The first 3 min of mixing comprises no vacuum suction to preserve the nanopowder, whereas a vacuum pressure of -10 bar was applied in the next 7 min to remove air bubbles<sup>11</sup>. To obtain a proper working time, we combined the accelerator at a base-to-catalyst ratio of 10:1 (according to the manufacturer instructions) with the modified silicone base for 5min with vacuum suction of -10 bar. The mixing was accomplished at a relative humidity (RH) of 50% ± 10% and temperature of 23 °C ± 2 °C <sup>12</sup>.

**Pouring the material into the mold:** The mixture was poured on the acrylic mold in excess amount to reduce the percentage of air bubbles that may be formed on the top surface of the samples when the cover was placed <sup>13</sup>. The cover was then applied and locked with screws, nuts, and G-clamps with a constant load application of 1 kg. The air bubbles on the specimen surface were removed by applying constant pressure until the material was completely cured<sup>13</sup>. The material was poured under standard conditions (RH of 50% ± 10% and temperature of 23 °C ± 2 °C) <sup>(14,15)</sup>.

**Specimen storage, retrieval, and finishing:** The specimens were reserved in a storage box (for constant results, atmospheric conditions that might affect the silicone properties were controlled) <sup>16</sup> for 16–72 h. Temperature must be within 20 °C – 25 °C, humidity should be within 50% – 60%, and care must be taken to avoid laying the specimens one over other<sup>17</sup>. Specimens were protected from light exposure from vulcanization to testing (the minimum time for vulcanization is 16 h) <sup>15</sup>. After polymerization, the specimens were removed from the molds. The tested specimens must remain intact with well-defined borders, free from air bubbles and clear from irregularities on the surface and inside, particularly at the stress-loaded areas <sup>17</sup>. Defects would cause the specimen to be discarded. Flashes of the specimens were removed with a scalpel and surgical blade no.11 <sup>17</sup>.

### Mechanical testing procedures:

**A) Tear strength:** Specimens were prepared and

tested in accordance with ASTM D624, 2013 (type C specimens)<sup>15</sup> by using a universal testing machine (Laryee Technology Co., Ltd., china) running at a velocity of 500 mm/min, by which specimens were stretched until complete rupturing at the apex. The following equation was applied: Tear strength =  $f/d$ , where  $f$  is the highest force recorded to rupture the specimen at the apex (kN) and  $d$  is the specimen average thickness (m).

**B) Hardness:** Specimens were prepared and tested in accordance with ISO 7619-1, 2010 (square specimens with 25 mm length and width and 6 mm thickness). A Shore A hardness digital tester (HT-6510A, China) with a dull indenter having a diameter of 1.25 mm was used<sup>18</sup>. The hardness value is the mean of five different measurements whose points lie at a distance of 6 mm from each other and from the border<sup>19</sup>.

**C) Tensile strength and elongation percentage:** The specimens were prepared and tested in accordance with ISO 37, 2011 (Type 2) in a dumbbell shape by using a universal testing machine running at a velocity of (500 mm/min) by which the specimen will be stretched until complete rupturing at the thin portion<sup>20</sup>. The tensile strength =  $F/A$ , where  $F$  expresses the highest force recorded to rupture the specimen at the thin portion (kN) and  $A$  expresses the specimen cross-sectional area ( $m^2$ ) (width x thickness)<sup>20</sup>. The elongation percentage can be calculated simultaneously where the specimen length at the beginning and the length at rupturing can be applied in the following equation:

Elongation percentage =  $(L_b - L^o)/L^o \times 100$ , where  $L^o$  is the original length (mm) and  $L_b$  is the extension at break (mm)<sup>20</sup>.

**D) Surface roughness:** The specimens resemble those of hardness with dimensions (25 mm×25 mm×6 mm). A digital surface roughness tester (SRT-6200S, China) was used, and its diamond probe acts by moving on the specimen surface. The average of three readings represents the surface roughness value of that specimen<sup>21</sup>.

**Additional tests:**

**A) Scanning electron microscopy (SEM):** An electron microscope (Inspect S50, FEI company, Netherland) was used to check the distribution of the NPs within the silicon matrix.

**B) Fourier transform infrared spectroscopy (FTIR):** A Fourier transform infrared spectrometer (Tensor 27, Bruker, Germany) was used to confirm whether or not a chemical reaction had occurred between the  $Y_2O_3$  nanopowder and the silicone elastomer.

**Statistical analysis:** The analysis was accomplished by an SPSS software with significance level set at  $p < 0.05$  and includes

- (1) Descriptive statistics: bar chart graphics.
- (2) Inferential statistics: ANOVA and post-hoc tests such as Levene, Tukey’s HSD, and Dunnett T3 tests.

**Findings**

**SEM and FTIR examinations:** SEM images show the well dispersion of the  $Y_2O_3$  NPs within the silicone matrix (Figure 1A and B). From the chemical point of view as shown in the FTIR spectrum, no interaction occurred between  $Y_2O_3$  nanopowder and VST50F maxillofacial silicone.

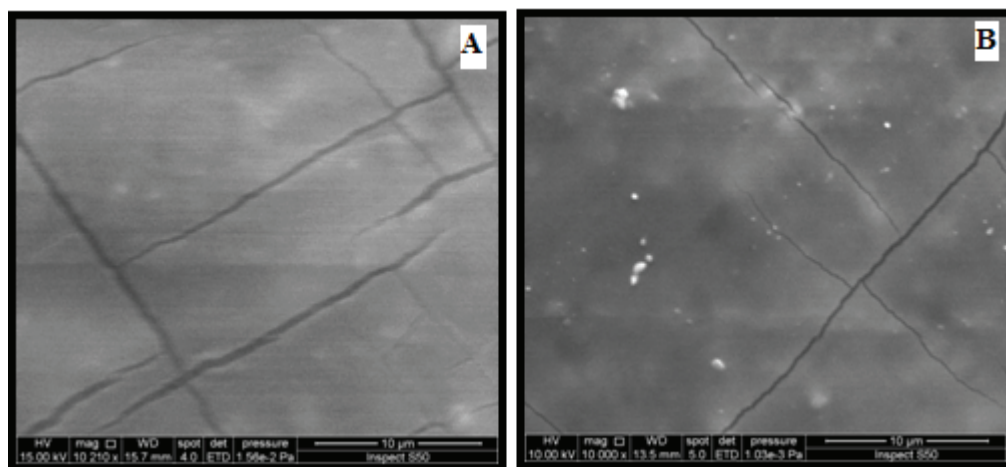


Figure 1: SEM of VST50F maxillofacial silicone (10 µm magnification) A, without the addition of nanofillers. B, with the addition of nanofillers.

**Tear strength:** The tear strength significantly increased after the addition of  $Y_2O_3$  ( $p < 0.05$ ) with groups B and C exhibiting higher means than group A (Table 1).

**Table 1: Descriptive statistics, one way ANOVA and Tukey’s HSD of tear strength.**

Tear strength (Pascal)					F	p value	Groups	p value
Groups	Min	Max	Mean	±SD				
A	27.5	30.4	28.50	.786	11.912	0.000 [HS]	A B	.025 S
B	28.9	34.8	30.50	1.944			A C	.000 HS
C	29.8	35.5	31.98	1.813			B C	.116 NS
Levene statistics=2.645, p value=0.089[NS]								

The highly significant increase in the tear strength may be related to the physically trapped networks formed due to the 3D cumulative capability of the NPs that creates networks of fillers within the polymer matrix. These trapped networks participate in hindering the movement of the polymer segment against the NP surface and preventing the movement of other polymer chains against each other, thereby changing the overall network density and markedly increasing polymer stiffness<sup>22</sup>.

**Hardness:** The hardness significantly increased after the addition of  $Y_2O_3$  ( $p < 0.05$ ) with groups B and C exhibiting higher means than group A (Table 2).

**Table 2: Descriptive statistics, one way ANOVA and Dunnett’s T3 of hardness.**

Hardness					F	p value	Groups	p value
Groups	Min	Max	Mean	±SD				
A	26.8	27.2	26.89	.137	86.669	.000 [HS]	A B	.000 HS
B	27.9	29.3	28.43	.488			A C	.000 HS
C	28.5	29.8	29.13	.445			B C	.011 S
Levene statistics=7.860, p value=0.002[HS]								

The highly significant increase in hardness may result from the filler-to-filler binding caused by increased concentration of nanofillers occupying the areas between polymer chains rendering them lesser. This phenomenon increases the rigidity of the polymer to resist penetration<sup>23</sup> and may also explain the significant difference between the two experimental groups where the addition of 1.5%  $Y_2O_3$  increases the hardness more than the addition of 1%  $Y_2O_3$ .

**Tensile strength:** The tensile strength increased non significantly after the addition of  $Y_2O_3$  ( $p > 0.05$ ) with groups B and C exhibited higher means than group A (Table 3).

**Table 3: Descriptive statistics and one way ANOVA of tensile strength.**

Tensile strength (MPa)					F	p value
Groups	Minimum	Maximum	Mean	±SD		
A	4.660	6.650	5.785	.615	.175	.841[NS]
B	4.840	6.420	5.859	.574		
C	4.930	6.760	5.942	.594		

The slight increase in tensile strength can be attributed to the physical interaction occurring between the NPs and the silicone matrix as polymer chains and the filler particles within slide over each other as a result of the applied tensile forces; the nanofiller presence prevents breakage of the polymer chains<sup>24</sup>.

**Elongation percentage:** The elongation percentage decreased non significantly after the addition of Y<sub>2</sub>O<sub>3</sub> ( $p > 0.05$ ) with group A had mean value higher than group B and C (Table 4).

**Table 4: Descriptive statistics and one way ANOVA of elongation percentage.**

Elongation percentage					F	p value
Groups	Minimum	Maximum	Mean	±SD		
A	5.570	6.940	6.365	.465	1.390	.266[NS]
B	5.270	6.830	6.115	.511		
C	5.130	6.940	5.973	.610		

The slight decrease in elongation percentages might be caused by the disruption of the proper orientation and flow of molecular chains, providing the matrix with additional restraint and causing earlier failure at several areas and eventually less elongation percentage values<sup>25</sup>.

**Surface roughness:** The surface roughness increased non significantly after the addition of Y<sub>2</sub>O<sub>3</sub> ( $p > 0.05$ ) with groups B and C exhibited higher means than group A (Table 5).

**Table 5: Descriptive statistics and one way ANOVA of surface roughness.**

Surface roughness(µm)					F	p value
Groups	Minimum	Maximum	Mean	±SD		
A	.25	.47	.370	.084	.044	.957[NS]
B	.29	.49	.372	.067		
C	.29	.44	.379	.049		

The randomly arranged NPs within the silicon matrix and on the specimen surface during preparation might increase the mean value of surface roughness after the addition of Y<sub>2</sub>O<sub>3</sub> nanopowder<sup>26</sup>.

### Conclusion

No chemical interaction occurred between the Y<sub>2</sub>O<sub>3</sub> NPs and VST50F silicone. The addition of Y<sub>2</sub>O<sub>3</sub> NPs to VST50F maxillofacial silicone improved the tear strength and slightly increased the tensile strength. The hardness also increased within the accepted clinical range, and the surface roughness slightly increased. The elongation percentage slightly decreased.

**Conflict of Interest:** We hereby declare no conflict of interest.

**Source of Funding:** Entirely self-funded.

**Ethical Clearance:** In vitro study.

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