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Effect of Polyester Fiber Incorporation into RTV Maxillofacial Silicone Elastomer on Tear Strength, Tensile Strength, Surface Roughness and Shore 'A' Hardness: A Pilot Study

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ABSTRACT

Aim: *The primary objective of the maxillofacial prosthesis is to restore the function and improve the esthetic; thereby benefit for the patient life quality, the aims of the present study were to select the proper percentage of fiber addition that improves the mechanical properties of the maxillofacial silicone.* ***Method:*** *Total 105 samples were fabricated by the addition of 0%, 0.25%, 0.5% and 0.75% by weight polyester fibers to A-2186 platinum RTV silicone elastomer after cutting into 2 mm and 4 mm length. The study samples were divided into three groups, each group containing 35 samples. One control group was prepared without polyester fibers addition and six other groups were prepared with different percentage of PA-6 micro particles 0.25%, 0.5% and 0.75% by weight and different fiber length (2 mm and 4 mm). Each group was further subdivided into three groups according to the conducted tests, i.e. tear and tensile strength, shore A hardness and surface roughness tests (n=5). The data were analyzed with a descriptive statistical analysis (mean, standard deviation, and bar chart representation).* ***Results:*** *The mean value of tear, tensile strength, surface roughness and shore A hardness for 0.25% by weight polyester fiber (2 mm length) reinforcement group increased significantly when compared to control group on the contrast to the other values of reinforcement groups which were deteriorated significantly.* ***Conclusion:*** *It was concluded that maxillofacial silicone elastomer mechanical properties can be improved when 0.25% by weight of 2 mm length polyester fiber added to it.*

Keywords: Polyester fiber, Tensile Strength, Silicone elastomer, Polyetherurethane, Platinum

INTRODUCTION

The maxillofacial defects can be caused by congenital abnormalities, surgical removal of tumors, trauma, or a combination of these occurrences [1,2]. They may result in destructive esthetic, functional, and psychological outcome and usually require risky and challenging procedures done by maxillofacial surgeons and prosthodontics team [3].

In the past many materials are used for construction of maxillofacial prosthesis. These may include wood, wax, and metals and in recently polymers.

Polymethylmethacrylate, polydimethylsiloxane and polyetherurethanes have been used in meeting the requirement and advantageous properties for materials that will be biocompatible, durable, color stable and easily manipulated [4].

The polyester fibers are resilient, resistant to wear, dimensionally stable, resistant to abrasion, have resistance to weathering and light exposure [5-7]. For these reasons the polyester fibers were chosen as reinforcing fibers for maxillofacial silicone in the present study.

The aims of the present pilot study were to select the proper amount of polyester fiber to be added to the maxillofacial silicone elastomeric materials to improve tear strength, tensile strength, surface roughness and shore 'A' hardness.

MATERIALS AND METHODS

The polyester fibers are cut into two lengths (2 mm and 4 mm) and added in concentration of (0.25%, 0.5% and 0.75%) by weight for each fiber length to platinum RTV elastomer A-2186 silicone and then tested. The results were compared to 0% without polyester fiber addition (control group). One handed five specimens were prepared and divided into three groups according to tests included in the study (tear strength, tensile strength, surface roughness and shore A hardness), each group contains 35 sample and they were subdivided according to the percentage used (0%, 0.25%, 0.5%, 0.75%) (n=5), The Shore A hardness samples were used for surface roughness measurements.

For tear strength test, all specimens were tested with a universal testing machine (WDW-20, Laryee Technology Co. Ltd., China) at 500 mm/min cross-head speed [8]. According to ISO 37 [9], 35 specimens of Type C which is an un-nicked specimen with a 90° angle on one side and with tab end specimens, were fabricated according to ASTM D624 [10] for tear strength test, 5 specimens were used as control group and the other 30 were silicone specimens after the addition of different concentrations of polyester fiber, (n=5) (Figure 1). Specimens were mounted in a computerized universal testing machine with a 30 ± 0.5 mm distance apart [11]. The maximum load was calculated by the machine software then the tear strength according to the following equation:

Tear strength = F/D

Where,

F: The maximum force required for specimen to break (KN).

D: The median thickness of each specimen (m).

Figure 1 Tear strength test sample

Total 35 specimens of Type 2 dumb-bell shape were fabricated for tensile strength, 5 specimens were used as control group and the other 30 were silicone specimens after the addition of different concentrations of polyester fibers, (n=5) (Figure 2). Specimens were mounted in a computerized universal testing machine 25 ± 0.5 mm apart [8]. The Maximum load was calculated by the machine software then the tensile strength was calculated according to the following equation:

Tensile strength = F/A

Where,

F: The maximum force recorded at break (N).

A: The original cross-sectional area of the specimen (mm^2).

Figure 2 Tensile strength specimens

According to ISO 7619-1:2010, 35 specimens fabricated, the sample used in shore A hardness test should have dimension 25 mm × 25 mm × 6 mm, with thickness of 6 mm, and the outer surface should mark with 5 points, one at center and four at corner with distance of 6 mm between points. The sample used for surface roughness test is the same that used for shore A hardness tests with dimension of 25 mm × 25 mm × 6 mm. Profilometer tester device used for making reading, it has stylus that moved over the surface of the sample and 3 reading is recorded for each sample, then the average value of the reading is considered as roughness results as shown in Figure 3.

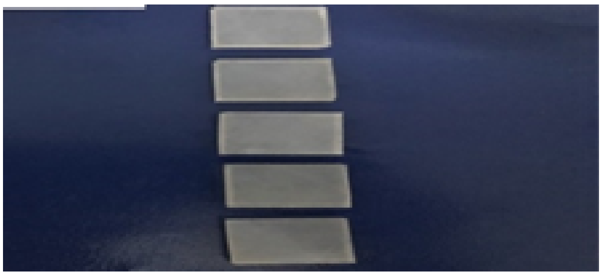

Figure 3 Shore A hardness and surface roughness samples

RESULTS

Tensile Strength Test

Results are listed in Table 1 and Figure 4. The 0.25% fiber percentage of 2 mm fiber length shows the highest mean among other groups.

Table 1 Tensile strength test results of pilot study (MPa)

Tensile strength in MPa (2 mm fibers length)				
Polyester fibers percentage	0%	0.25%	0.50%	0.75%
Mean	4.4	5.05	4.2	3.7
SD	0.128	0.037	0.231	0.192
Tensile strength in MPa (4 mm fibers length)				
Polyester fiber percentage	0%	0.25%	0.50%	0.75%
Mean	4.4	3.5	3.7	3.7
SD	0.128	0.287	0.183	0.448

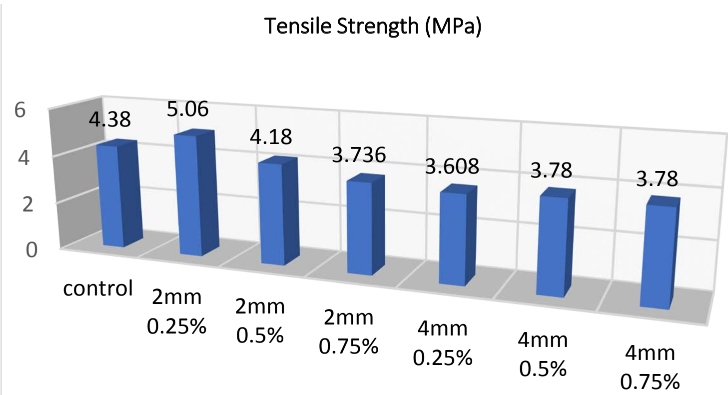

Figure 4 Bar chart representing tensile strength test results

ANOVA table with LSD multiple comparison revealed there was highly significant differences among all groups when $p<0.05$ (Table 2).

Table 2 ANOVA Table for tensile strength test

Groups	Sum of Squares	Df	Mean Square	F	Significance
Between Groups	7.907	6	1.318	17.297	High
Within Groups	2.133	28	0.076	-	-
Total	10.04	34	-	-	-

There is no significant difference between control group and 0.5% by wt. concentration of 2 mm polyester fiber in addition there is no significant differences between 0.75% of 2 mm length polyester fibers and 0.25%, 0.5%, 0.75% by wt. concentration of 4 mm polyester fiber (Table 3).

Table 3 Multiple comparison LSD for tensile strength test

Groups		Mean Difference (I-J)	Significance
Control	2 mm, 0.25%	-0.68	0.001
	2 mm, 0.5%	0.2	0.262
	2 mm, 0.75%	0.644	0.001
	4 mm, 0.25%	0.772	0.00
	4 mm, 0.5%	0.6	0.002
	4 mm, 0.75%	0.6	0.002
2 mm, 0.25%	2 mm, 0.5%	0.88	0.00
	2 mm, 0.75%	1.324	0.00
	4 mm, 0.25%	1.452	0.00
	4 mm, 0.5%	1.28	0.00
	4 mm, 0.75%	1.28	0.00
2 mm, 0.5%	2 mm, 0.75%	0.444	0.017
	4 mm, 0.25%	0.572	0.003
	4 mm, 0.5%	0.4	0.03
	4 mm, 0.75%	0.4	0.03
2 mm, 0.75%	4 mm, 0.25%	0.12	0.47
	4 mm, 0.5%	-0.044	0.803
	4 mm, 0.75%	-0.044	0.803
4 mm, 0.25%	4 mm, 0.5%	-0.172	0.333
	4 mm, 0.75%	-0.172	0.333
4 mm, 0.5%	4 mm, 0.75%	0.00	1.00

Tear Strength Test

Results are listed in Table 4 and Figure 5. The 0.5% fiber percentage of 2 mm fiber length shows the highest mean among other groups.

Table 4 Tear strength test results of pilot study (KN/m)

Tear strength in N/mm (2 mm fibers length)				
Polyester fiber percentage	0%	0.25%	0.50%	0.75%
Mean	24.2	24.1	24.3	23.4
SD	0.57	0.98	1.6	0.97
Tear strength in N/mm (4 mm fibers length)				
Polyester fiber percentage	0%	0.25%	0.50%	0.75%
Mean	24.2	18.3	20.46	20.4
SD	0.57	0.82	0.41	1.6

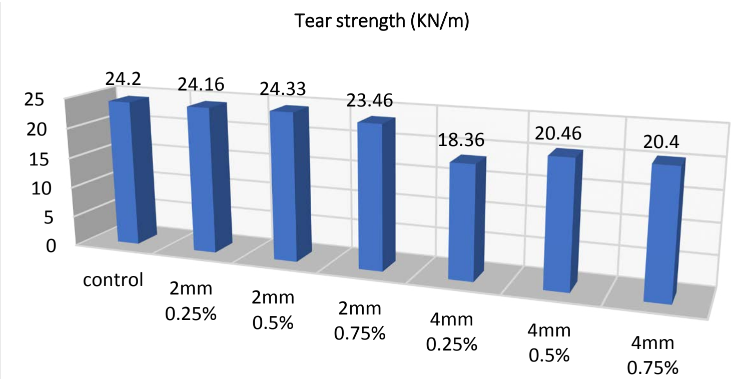

Figure 5 Bar chart represents tear strength test results

Further comparison made by using ANOVA table with LSD multiple comparison which revealed that high significant differences observed among all groups (Table 5).

Table 5 ANOVA table for tear strength test

Groups	Sum of Squares	df	Mean Square	F	Significance
Between Groups	165.741	6	27.623	29.992	High
Within Groups	25.789	28	0.921	-	-
Total	191.53	34	-	-	-

When comparing the groups by LSD multiple comparison, control group shows no significant differences with 2 mm polyester fiber length in a concentration of 0.25%, 0.5% and 0.75% by wt., also 0.25% by wt. of 2 mm polyester fiber length group shows no significant results when compared with 2 mm fiber length (0.5% and 0.75% by wt. concentration), in addition to that 0.5% by wt. polyester fiber concentration of 2 mm length shows no significant results when compared with 0.75% by wt. of 2 mm polyester fiber length. 4 mm fiber length of 0.25% and 0.5% by wt. concentrations shows no significant results when compared with 0.75% by wt. polyester fiber of 4 mm length (Table 6).

Table 6 Multiple comparison LSD for tear strength test

(I) Groups		Mean Difference (I-J)	Sig.
Control	2 mm, 0.25%	0.11556	0.85
	2 mm, 0.5%	0.00444	0.994
	2 mm, 0.75%	0.82222	0.186
	4 mm, 0.25%	5.80889*	0.00
	4 mm, 0.5%	3.72889*	0.00
	4 mm, 0.75%	3.65333*	0.00
2 mm, 0.25%	2 mm, 0.5%	-0.11111	0.856
	2 mm, 0.75%	0.70667	0.254
	4 mm, 0.25%	5.69333*	0.00
	4 mm, 0.5%	3.61333*	0.00
	4 mm, 0.75%	3.53778*	0.00
2 mm, 0.5%	2 mm, 0.75%	0.81778	0.189
	4 mm, 0.25%	5.80444*	0.00
	4 mm, 0.5%	3.72444*	0.00
	4 mm, 0.75%	3.64889*	0.00
2 mm, 0.75%	4 mm, 0.25%	2.90667*	0.00
	4 mm, 0.5%	2.83111*	0.00
	4 mm, 0.75%	-5.80889*	0.00
4 mm, 0.25%	4 mm, 0.5%	2.08000*	0.002
	4 mm, 0.75%	-0.07556	0.902
4 mm, 0.5%	4 mm, 0.75%	0.07556	0.902

Shore A Hardness

Results are listed in Table 7 and Figure 6. The 0.75% fiber percentage of 4 mm fiber length shows the highest mean among other groups.

Table 7 Shore A hardness results of pilot study

Shore A hardness (2 mm fibers length)				
Polyester fiber percentage	0%	0.25%	0.50%	0.75%
Mean	36.8	37.6	43.8	41.8
SD	1.72	1.02	0.75	2.32
Shore A hardness (4 mm fibers length)				
Polyester fiber percentage	0%	0.25%	0.50%	0.75%
Mean	36.8	39	39.4	44.2
SD	1.72	0.63	2.65	5.5

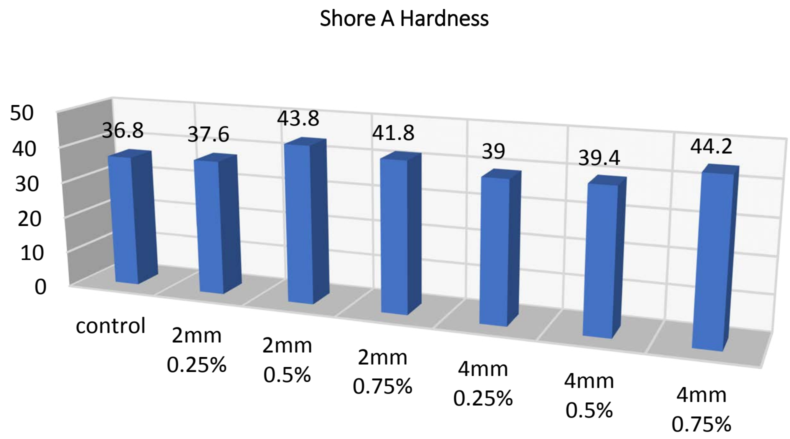

Figure 6 Bar chart represents shore A hardness test results

ANOVA table with LSD multiple comparison revealed a high significant difference among all groups included in the study (Table 8).

Table 8 ANOVA table for shore A hardness test

Groups	Sum of Squares	df	Mean Square	F	Significance
Between Groups	7.907	6	1.318	17.297	High
Within Groups	2.133	28	0.076	-	-
Total	10.04	34	-	-	-

LSD multiple comparison test shows that 0.25% by wt. concentration of 2 mm polyester fiber length no significant results when compared with control, 4 mm fiber length (0.25% and 0.5% by wt. concentration), while 2 mm polyester fiber length of 0.5% by wt. concentration shows no significant results when compared with 0.7% by wt. concentration (2 mm and 4 mm). In addition, 2 mm polyester fiber length of 0.75% by wt. concentration shows no significant differences when compared with 4 mm polyester fiber length of o.25%, 0.5% and 0.75% by wt. fiber concentration. 0.25% by wt. concentration of 4 mm fiber length shows no significant results when compared with 0.5% by wt. concentration of 4 mm fiber length (Table 9).

Table 9 Multiple comparison LSD for shore A hardness test

Groups		Mean Difference (I-J)	Sig.
Control	2 mm, 0.25%	-0.8	0.667
	2 mm, 0.5%	-7	0.001
	2 mm, 0.75%	-5	0.011
	4 mm, 0.25%	-2.2	0.242
	4 mm, 0.5%	-2.6	0.169
	4 mm, 0.75%	-7.4	0.00
2 mm, 0.25%	2 mm, 0.5%	-6.2	0.002
	2 mm, 0.75%	-4.2	0.03
	4 mm, 0.25%	-1.4	0.454
	4 mm, 0.5%	-1.8	0.337
	4 mm, 0.75%	-6.6	0.001
2 mm, 0.5%	2 mm, 0.75%	2	0.287
	4 mm, 0.25%	4.8	0.015
	4 mm, 0.5%	4.4	0.024
	4 mm, 0.75%	-0.4	0.83
2 mm, 0.75%	4 mm, 0.25%	2.8	0.14
	4 mm, 0.5%	2.4	0.203
	4 mm, 0.75%	-2.4	0.203

4 mm, 0.25%	4 mm, 0.5%	-0.4	0.83
	4 mm, 0.75%	-5.2	0.009
4 mm, 0.5%	4 mm, 0.75%	-4.8	0.015

Surface Roughness

Results are listed in Table 10 and Figure 7. The 0.75% fiber percentage of 4 mm fiber length shows the highest mean among other groups.

Table 10 surface roughness results of pilot study (µm)

Surface Roughness (2 mm fibers length)				
Polyester fiber percentage	0%	0.25%	0.50%	0.75%
Mean	0.29	0.41	0.46	0.73
SD	0.0004	0.0004	0.002	0.0008
Surface Roughness (4 mm fibers length)				
Polyester fiber percentage	0%	0.25%	0.50%	0.75%
Mean	0.29	0.48	0.69	0.75
SD	0.0004	0.0008	0.0008	0.0004

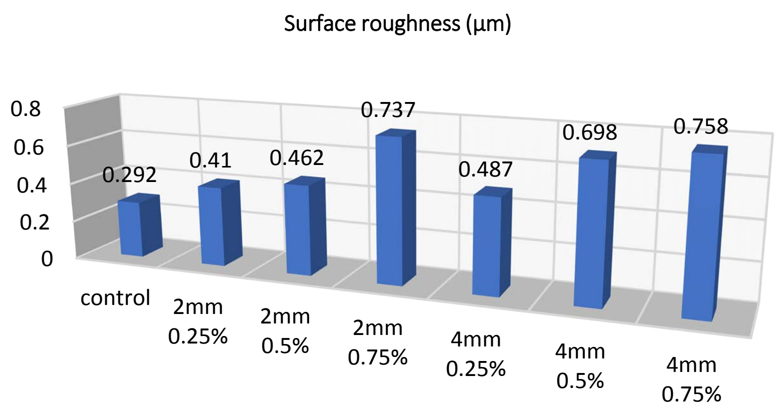

Figure 7 Bar chart representing surface roughness test results

Further comparison made by using ANOVA table with LSD multiple comparisons which revealed that high significant differences found among all groups tested (Tables 11 and 12).

Table 11 ANOVA Table for Surface roughness test

Groups	Sum of Squares	Df	Mean Square	F	Significance
Between Groups	0.99	6	0.165	276956.56	High
Within Groups	0.00	28	0.00	-	-
Total	0.99	34	-	-	-

Table 12 Multiple comparison LSD for surface roughness test

(I) Groups		Mean Difference (I-J)	Significance
Control	2 mm, 0.25%	-0.1179	0.00
	2 mm, 0.5%	-0.1695	0.00
	2 mm, 0.75%	-0.4445	0.00
	4 mm, 0.25%	-0.1945	0.00
	4 mm, 0.5%	-0.4055	0.00
	4 mm, 0.75%	-0.4662	0.00

2 mm, 0.25%	2 mm, 0.5%	-0.0515	0.00
	2 mm, 0.75%	-0.3266	0.00
	4 mm, 0.25%	-0.0766	0.00
	4 mm, 0.5%	-0.2876	0.00
	4 mm, 0.75%	-0.3483	0.00
2 mm, 0.5%	2 mm, 0.75%	-0.275	0.00
	4 mm, 0.25%	-0.025	0.00
	4 mm, 0.5%	-0.236	0.00
	4 mm, 0.75%	-0.2967	0.00
2 mm, 0.75%	4 mm, 0.25%	0.25	0.00
	4 mm, 0.5%	0.039	0.00
	4 mm, 0.75%	-0.0217	0.00
4 mm, 0.25%	4 mm, 0.5%	-0.211	0.00
	4 mm, 0.75%	-0.2717	0.00
4 mm, 0.5%	4 mm, 0.75%	-0.0607	0.00

DISCUSSION

Despite of wide use of silicone elastomers, they are far away from approaching ideal properties. Maxillofacial prostheses made of silicone elastomer require replacement as early as 6 months and can last up to 24 months [12]. Silicone generally exposed to deterioration in their physical and mechanical properties, color change, and loss of the retentive substrate. Such problems become the interesting subject for numerous studies that investigating properties (i.e., tensile strength, tear strength, surface roughness and surface hardness) [12].

The mechanical properties of silicone elastomer are dependent on many factors. The most important one of these is the molecular weight distribution which has great effect on the mechanical properties of the material. The process of blending of both long and short chains of the same polymer produce a wider and bimodal molecular weight distribution, and a network produced from that blending is known as a bimodal network [13].

Reinforcement by fiber is depending on various variables including, fiber type, length, and form, and arrangement, percentages of fibers in the polymeric matrix and fiber matrix interaction and presence or absence of salination. Polyester fibers are available in filament form and considered as thermoplastic polyester group. They are sensitive to temperature and have hydrophobic behavior [14]. Polyester fibers have low moisture absorption, high resiliency and dimensional stability, excellent wear resistance, good weather and light resistance, good abrasion resistance and good blending ability. They are relatively flame resistant, resistant to micro-organisms growth and biologically inert [5].

The results of tensile strength test shown in Table 1 and Figure 4 indicated that tensile strength is increased in 0.25% polyester fibers concentration (2 mm fiber length) and decreased in other concentration when compared to the unreinforced silicone. This could be due to the chemical and physical interactions of polyester with the polymer chains. Tensile strength of cured silicone elastomer depends mainly on the cross-linking system, cross-linking density and the interaction between fillers and polymer chains [15].

Tensile strength results of this study agree with Guany in 2008 [16] who found the incorporation of tulle to RTV silicone improve the tensile when compared to non-reinforced silicone.

The reasons why the results of the tear strength how decrease at fibers concentration (0.5%) and other concentration may be attributed for two possible causes. Firstly creating a stress concentration points at the surface of the specimen by polyester fibers aggregation which might be the consequence of micro cracks emerging between the filler and the matrix, which would cause an early failure of the silicone material .The possible second reason is failure of the material from infiltrating into the accumulated polyester fibers, which would result in a void and deterioration that would make the tear strength less than the other groups. This may explain the reason for using an appropriate type and quantity of polyester fibers. The results of tear strength studies using platinum A-2186 silicone was high in some studies and low in others when same methodologies and techniques of testing were used.

CONCLUSION

The results of surface roughness indicated increase of roughness values with increased polyester fibers concentration in A-2186 silicone elastomer when compared with non-reinforced silicone. For instance, it has been evaluated that the fine random dispersion of Carbone nanotubes in PDMS, forming PDMS/CNT composites lead to increase the surface roughness [17].

The increase in surface hardness was directly proportional to the increase of polyester fibers concentration. This could be due to dispersing of polyester fibers in the silicone elastomer, which increases the cross-link density, thereby leading to increased hardness. The result of study is in agreement with Andreopoulos, et al. in 1994 [18] who evaluated the addition of different fibers into elastomeric silicone. The study performs the addition of short glass fibers, aramid fibers and ultrahigh modulus polyethylene fibers. The result of study shows significant increase of material hardness.

DECLARATION

Conflict of Interest

The authors and planners have disclosed no potential conflicts of interest, financial or otherwise.

REFERENCES

[1] Huber, Heidi, and Stephan P. Studer. “Materials and techniques in maxillofacial prosthodontic rehabilitation.” *Oral and maxillofacial Surgery Clinics of North America,* Vol. 14, No. 1, 2002, pp. 73-93.

[2] Lemon, James C., et al. “Facial prosthetic rehabilitation: Pre-prosthetic surgical techniques and biomaterials.” *Current Opinion in Otolaryngology & Head and Neck Surgery,* Vol. 13, No. 4, 2005, pp. 255-62.

[3] Kurunmäki, Hemmo, et al. “A fiber-reinforced composite prosthesis restoring a lateral midfacial defect: a clinical report.” *Journal of Prosthetic Dentistry,* Vol. 100, No. 5, 2008, pp. 348-52.

[4] Lontz, J.F., Schweige. JW, and A.W. Burger. “Modifying stress-strain profiles of polysiloxane elastomers for improved maxillofacial conformity.” *Journal of Dental Research*, Vol. 53. No. Feb. 1619 duke St, Alexandria, VA 22314: American Association Dental Research, 1974.

[5] Militky, Jiri. “The chemistry, manufacture and tensile behavior of polyester fibers.” *Handbook of Tensile Properties of Textile and Technical Fibres Woodhead Publishing Series in Textiles*, edited by A. R. Bunsell, Elsevier, 2009, pp. 223-24.

[6] Hatamleh, Muhanad M., et al. “Mechanical properties and simulated aging of silicone maxillofacial elastomers: Advancements in the past 45 years.” *Journal of Prosthodontics,* Vol. 25, No. 5, 2016, pp. 418-26.

[7] Malheiros-Segundo, Antônio de Luna, et al. “Effect of a denture cleanser on hardness, roughness and tensile bond strength of denture liners.” *Brazilian Journal of Oral Sciences*, Vol. 7, No. 26, pp. 1596-1601.

[8] Zayed, Sara M., Ahmad M. Alshimy, and Amal E. Fahmy. “Effect of surface treated silicon dioxide nanoparticles on some mechanical properties of maxillofacial silicone elastomer.” *International Journal of Biomaterials,* Vol. 2014, 2014.

[9] ISO, BS. “37: 2011 Rubber, vulcanized or thermoplastic-Determination of tensile stress-strain properties.” British Standards Institution (BSI), London (2011).

[10] ASTM D624-00. Standard test method for tear strength of conventional vulcanized rubber and thermoplastic elastomers. ASTM International, West Conshohocken, PA, USA. 2012.

[11] Al-Harbi, Fahad A., et al. “Mechanical behavior and color change of facial prosthetic elastomers after outdoor weathering in a hot and humid climate.” *Journal of Prosthetic Dentistry,* Vol. 113, No. 2, 2015, pp. 146-51.

[12] Hatamleh, Muhanad M., and David C. Watts. “Mechanical properties and bonding of maxillofacial silicone elastomers.” *Dental Materials*, Vol. 26, No. 2, 2010, pp. 185-91.

[13] Shah, Gul Bali, and Ray Wlliam Winter. “Effect of bimodality on tear properties of silicone networks.” *Macromolecular Chemistry and Physics,* Vol. 197, No. 7, 1996, pp. 2201-08.

[14] Hachim, Thikra M., Zainab S. Abdullah, and Yasamin T. Alausi. “Evaluation of the effect of addition of polyester fiber on some mechanical properties of heat cure acrylic resin.” *Journal of Baghdad College of Dentistry,* Vol. 25, Special Is, 2013, pp. 23-29.

[15] Aziz, Tariq, Mark Waters, and Robert Jagger. "Analysis of the properties of silicone rubber maxillofacial prosthetic materials." *Journal of Dentistry*, Vol. 31, No. 1, 2003, pp. 67-74.

[16] Gunay, Yumushan, et al. "Effect of tulle on the mechanical properties of a maxillofacial silicone elastomer." Dental Materials Journal, Vol. 27, No. 6, 2008, pp. 775-79.

[17] Beigbeder, Alexandre, et al. "On the effect of carbon nanotubes on the wettability and surface morphology of hydrosilylation-curing silicone coatings." *Journal of Nanostructured Polymers and Nanocomposites,* Vol. 5, No. 23, 2009, pp. 37-43.

[18] Andreopoulos, A.G., and M. Evangelatou. "Evaluation of various reinforcements for maxillofacial silicone elastomers." *Journal of Biomaterials Applications*, Vol. 8, No. 4, 1994, pp. 344-60.