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Research Article

Evaluation of Some Mechanical Properties of a Maxillofacial Silicon Elastomer Reinforced with Polyester Powder

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Maxillofacial silicone elastomers are used to replace and reconstruct missing facial parts for patients with trauma or a certain disease. Although commonly favorable silicone elastomers are not ideal in properties, many studies have been carried out to improve their mechanical properties and to come out with ideal maxillofacial prosthetic materials, so as to render patients with the best maxillofacial prostheses. The aim of the current study is to evaluate the effect of addition of different concentrations of polyester powder on hardness, tear strength, surface roughness, and tensile strength of maxillofacial A-2186 RTV silicone elastomers. Polyester powder was added to the silicone elastomer in the concentrations of 1%, 3% and 5% by using an electronic digital balance, compared with the control group of 0% polyester filler. The shore A hardness test was done according to ASTM D 2240 standards. The tear test was done according to ASTM D624 type C standards. The tensile test was done according to ISO specification number 37:2011. The surface roughness test was performed according to ISO 7619-1 2010 specifications. The data collected were then analyzed using one-way analysis of variance (ANOVA) and post hoc and Fisher's LSD tests. All three groups showed a highly significant increase in tear strength, tensile strength, hardness, and roughness, compared to the control group. Reinforcement of A-2186 Platinum RTV Silicone Elastomer with 5% polyester significantly improved the mechanical properties tested in this study.

1. Introduction

The occurrence of high rate of injuries because of terrorist attacks on civilian and military personnel made it necessary for maxillofacial specialists to select the most suitable materials for those who are in danger of maxillofacial trauma and prepare for rehabilitation [1].

When surgical rehabilitation for patients with maxillofacial defects cannot be applied because of missing of excessive substances or some psychophysical conditions related to patients who reject surgical procedure, prosthetic rehabilitation will be a surgical alternative to facial reconstruction and reestablishing their self-esteem and confidence [2].

Patients undergoing prosthodontic treatment in general and maxillofacial treatment in particular require prostheses that could restore function and esthetic [3, 4]. In maxillofacial prostheses, the material used to replace living tissue in the face such as the noses or eyes should have sufficient strength, which means adequate flexibility and amount of elongation of materials during removing the prosthesis at night time for cleaning [5]. Silicone elastomers are considered as the desirable material for facial prosthesis fabrication [6].

Various research studies investigating the mechanical properties of maxillofacial silicone materials illustrate that the maxillofacial silicone is still far from being ideal in properties to fulfill the required material for maxillofacial prosthesis; for this reason, reinforcement with different additives is required to improve the physical and mechanical properties of maxillofacial silicone elastomeric materials [7–9].

The purpose of this research is mainly to evaluate the effect of polyester powder with different weight percentage concentrations (1%, 3%, and 5%) on some mechanical properties (shore A hardness, tear strength, surface roughness, and tensile strength) of A-2186 RTV silicone elastomer.

2. Material and Method

This study investigated the effect of the addition of polyester macro-powder with particle size ranging from 50–120 micrometers (Goodfellow, Cambridge Limited, England) on A-2186 Platinum RTV Silicone Elastomer (Factor II Inc., Lakeside, AZ, USA).

Four groups of materials were made according to the concentration of polyester (0% as control, 1%, 3% and 5%) by using an electronic digital balance. The laser engraving cutting machine was used (JL-1612, Jinan Link Manufacture & Trading Co., Ltd., China) to prepare molds according to specifications for each test (the tear strength test according to ASTM D624 type C standards, the tensile strength test according to ISO specification number 37:2011, the hardness test according to ASTM D2240 standards, and the surface roughness test according to ISO 7619-1 2010 specifications) and bottom and cover parts were made with 4 ± 0.05 mm thickness [10–12].

By using a vacuum mixer (Multivac 3, Degussa, Germany), silicon (part A) was added to polyester powder and mixed first for 3 minutes without vacuuming to avoid filler suction, and then for 7 minutes under vacuuming (–10 bar) at 360 rpm speed. After that, the silicone cross linker (part B) was added to the mixture and remixed under vacuum for 5 minutes to obtain a homogenous bubble-free mixture [13].

For the 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. According to ISO 37, the specimens were fabricated according to ASTM D624 for the tear strength test. The maximum load was calculated by the machine software, and then the tear strength was calculated according to the following equation:

$$\text{tear strength} = \frac{F}{D}, \quad (1)$$

where F is the maximum force required for the specimen to break (kN) and D is the median thickness of each specimen (m).

Total specimens of Type 2 dumb-bell shape were fabricated for tensile strength. The specimens were mounted on a computerized universal testing machine (25 ± 0.5 mm). According to the specification of ISO 37:2011, sample thickness at the center and at each end was measured by using a digital caliper, and then the mean of measurements was taken. Demarking the samples was about 10 mm away from each end symmetrically. The samples were stretched at a rate of 500 mm/min, and the maximum force reading was recorded after breakage of the samples. The maximum load was calculated by the machine software, and then the tensile strength was calculated according to the following equation:

$$\text{tensile strength} = \frac{F}{A}, \quad (2)$$

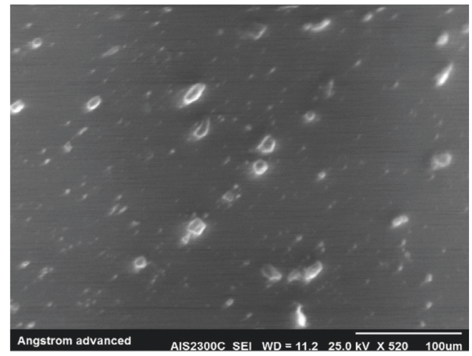

Figure 1: 1% by weight polyester powder group.

Figure 2: 3% by weight polyester powder group.

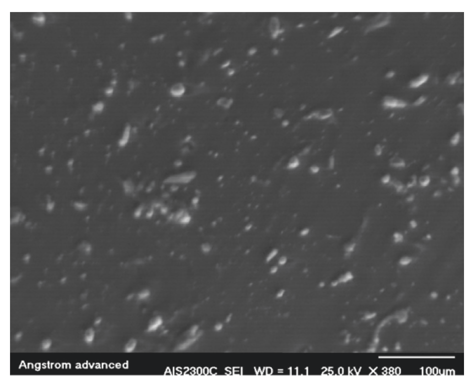

Figure 3: 5% by weight polyester powder group.

where F is the maximum force recorded at break (N) and A is the original cross-sectional area of the specimen (mm^2).

According to ISO 7619-1:2010, 35 specimens were fabricated, and the sample used in the shore A hardness test should have the dimension of 25 mm × 25 mm × 6 mm, with thickness of 6 mm, and the outer surface should mark with 5 points, one at the center and four at the corner with a distance of 6 mm between points. Measurements were done using a shore A hardness durometer. The indenter of the durometer was penetrated on the sample surface at the five points previously marked, the durometer was pressed firmly for 3 seconds, and the mean of 6 readings was recorded.

The samples used for the surface roughness test were the same as that used for the shore A hardness test, with a

Table 1: Descriptive statistics and one-way analysis of variance (ANOVA) for hardness, tear strength, tensile strength, and roughness.

		N	Mean	Std. deviation	Std. error	95% confidence interval for mean		Minimum	Maximum
						Lower bound	Upper bound		
Roughness (μm)	0%	10	0.4507	0.03858	0.01220	0.4231	0.4783	0.40	0.50
	1%	10	0.4415	0.03904	0.01234	0.4136	0.4694	0.36	0.49
	3%	10	0.4316	0.01891	0.00598	0.4181	0.4451	0.41	0.46
	5%	10	0.4822	0.06560	0.02075	0.4353	0.5291	0.41	0.62
Tensile (MPa)	0%	10	4.8850	0.45344	0.14339	4.5606	5.2094	4.50	5.90
	1%	10	5.0100	0.11547	0.03651	4.9274	5.0926	4.91	5.21
	3%	10	4.5900	0.38632	0.12217	4.3136	4.8664	4.12	5.00
	5%	10	4.4110	0.21179	0.06697	4.2595	4.5625	4.21	4.75
Tear (kN/m)	0%	10	20.7700	2.40557	0.76071	19.0492	22.4908	15.50	23.60
	1%	10	23.4800	0.76274	0.24120	22.9344	24.0256	22.00	24.50
	3%	10	21.9500	2.97630	0.94119	19.8209	24.0791	19.00	27.00
	5%	10	20.0000	0.74536	0.23570	19.4668	20.5332	19.00	21.00
Hardness (mm)	0%	10	30.7300	1.72501	0.54550	29.4960	31.9640	28.10	33.10
	1%	10	31.0400	1.72511	0.54553	29.8059	32.2741	28.10	33.40
	3%	10	34.3100	1.51617	0.47946	33.2254	35.3946	33.00	38.30
	5%	10	34.6750	1.28609	0.40670	33.7550	35.5950	33.20	36.70

dimension of $25\,mm \times 25\,mm \times 6\,mm$. The profilometer tester was used for making readings, and then the average value of 6 readings was considered as roughness results.

The mold was first brushed using the separating medium and should be left to dry before use, and then the mixture was poured and the mold was closed using G-clamps and screws [10]. The silicone should be set aside for 24 hours at $23 \pm 2°C$ and a relative humidity of $50\% \pm 10\%$ for complete setting (according to the manufacturer's instructions) [9]. After completing polymerization, the specimens have been separated from the mold by using suitable cutting dies aided by custom- made specimen cutting press (3 ton-capacity hydraulic Jack; Lezaco, Syria), and then they were checked for any bubbles, defects, or surface irregularities [14, 15]. Finally, SEM analysis was done for the silicone elastomer after polyester fillers were added at 1%, 3%, and 5% by weight.

2.1. Statistical Analysis. The data were analyzed using SPSS statistical analysis software version 23, and the ANOVA table and the LSD multiple comparison test were used to show the significant differences among groups.

3. Results

The SEM results of the silicone elastomer after reinforcement with 2 mm length polyester powder at 1%, 3%, and 5% by weight are illustrated in Figures 1–3, respectively.

All groups showed that the mean values for tear strength, tensile strength, roughness, and hardness have significantly increased in certain concentrations in comparison with the control group (0% by weight concentration polyester powder). Thus, hardness was resulted to be the highest in 5% by weight polyester powder concentration. While 1% by weight polyester produced the highest tear strength as compared with other concentrations.

The same was with the tensile strength because 1% polyester concentration showed the highest mean value among others. On the other hand, the mean value obtained from 5% polyester was the highest for the roughness test. Table 1 illustrated the mean values obtained from the analysis of the results.

The ANOVA test showed that there was no significant effect in the tear strength, tensile strength, and hardness tests ($P = 0.002$, $P = 0.001$, $P = 0.000$), while a significant effect was found in the maxillofacial silicone elastomeric material for the roughness test ($P = 0.075$) compared with the control group ($P > 0.01$), as illustrated in Table 2. Furthermore, Table 3 illustrates the post hoc test results in detail.

4. Discussion

Essential properties have to be achieved in maxillofacial silicone elastomers such as high tensile strength, adequate hardness, and high tear resistance. Silicone elastomers are widely used due to the desirable properties, and variations in their properties are attributed to differences in the formulations of the material [16, 17].

Clinically, a silicone maxillofacial prosthesis functions for almost two years. Then, the prosthesis should be re-made for the reason of degradability of the mechanical properties of silicon elastomeric materials. Maxillofacial silicones that exhibit favorable mechanical properties are successfully used as a facial prosthesis [18].

Chemically, the interaction between polymer chains and silica fillers affect the overall silicone strength [19] and causes early deterioration of silicone, which in turn leads to texture modification, shape changes, and tear strength reduction [20].

Although silicon elastomers are far from ideal, they are still favorable among all different materials, and research is carried out to improve their properties to make them "ideal maxillofacial prosthetic materials" [21]. Altering the ratio of the matrix and the filler particles can make an ideal maxillofacial silicone elastomer. Modifying elastomers with reinforcing additives is one of the ways to improve the

Table 2: One-way ANOVA showing significant difference between all tested groups.

Mechanical properties		Sum of squares	*df*	Mean square	*F*	Sig.
Roughness	Between groups	0.014	3	0.005	2.501	0.075
	Within groups	0.069	36	0.002		
	Total	0.083	39			
Tensile	Between groups	2.236	3	0.745	7.219	0.001
	Within groups	3.717	36	0.103		
	Total	5.954	39			
Tear	Between groups	68.958	3	22.986	5.826	0.002
	Within groups	142.042	36	3.946		
	Total	211.000	39			
Hardness	Between groups	131.287	3	43.762	17.674	0.000
	Within groups	89.140	36	2.476		
	Total	220.427	39			

Table 3: Post hoc test showing significant difference between all tested groups.

Multiple comparisons

LSD

Dependent variable	(I) VAR00002 (%)	(J) VAR00002 (%)	Mean difference (I–J)	Std. error	Sig.	95% confidence interval	
						Lower bound	Upper bound
Roughness	0	1	0.00920	0.01959	0.641	−0.0305	0.0489
		2	0.01910	0.01959	0.336	−0.0206	0.0588
		3	−0.03150	0.01959	0.117	−0.0712	0.0082
	1	2	0.00990	0.01959	0.616	−0.0298	0.0496
		3	−0.04070*	0.01959	0.045	−0.0804	−0.0010
	2	3	−0.05060*	0.01959	0.014	−0.0903	−0.0109
Tensile	0	1	−0.12500	0.14371	0.390	−0.4165	0.1665
		2	0.29500*	0.14371	0.047	0.0035	0.5865
		3	0.47400*	0.14371	0.002	0.1825	0.7655
	1	2	0.42000*	0.14371	0.006	0.1285	0.7115
		3	0.59900*	0.14371	0.000	0.3075	0.8905
	2	3	0.17900	0.14371	0.221	−0.1125	0.4705
Tear	0	1	−2.71000*	0.88833	0.004	−4.5116	−0.84
		2	−1.18000	0.88833	0.192	−2.9816	0.6216
		3	0.77000	0.88833	0.392	−1.0316	2.5716
	1	2	1.53000	0.88833	0.094	−0.2716	3.3316
		3	3.48000*	0.88833	0.000	1.6784	5.2816
	2	3	1.95000*	0.88833	0.035	0.1484	3.7516
Hardness	0	1	−0.31000	0.70372	0.662	−1.7372	1.1172
		2	−3.58000*	0.70372	0.000	−5.0072	−2.1528
		3	−3.94500*	0.70372	0.000	−5.3722	−2.5178
	1	2	−3.27000*	0.70372	0.000	−4.6972	−1.8428
		3	−3.63500*	0.70372	0.000	−5.0622	−2.2078
	2	3	−0.36500	0.70372	0.607	−1.7922	1.0622

*The mean difference is significant at the 0.05 level.

physical and mechanical properties of maxillofacial elastomeric materials [22, 23].

Reinforcement of maxillofacial elastomers to a certain level significantly improves their mechanical properties. This process depends much on the properties of the polymer used, characteristics of fillers such as particle size, amount of filers, and processing conditions [24]. Hence, polyester was added at various proportions to develop various mechanical properties so as to achieve maxillofacial prosthetics requirements. This can be seen in the SEM images that polyester at 5% concentration has more homogenous distribution in the matrix (Figure 3).

The results of the current study indicate that incorporation of polyester at 1%, 3% and 5% concentrations by weight into maxillofacial silicone made significant difference in material roughness especially in 5% concentration, and also hardness increased in 5% concentration. This may have been resulted because the increase in filler concentration increases both intermolecular forces and adsorption of the polymer chain on the filler surface [25], yet the addition of polyester showed no statistically significant effect on the hardness of the silicon elastomeric material.

On the other hand, tear strength was significantly different in 1% concentration, and accordingly, tensile strength was significantly different in 1% concentration. Although it had no significant effect on the material, tear strength might have increased due to the polymer ability to make strain energy and dissipate it near the growing crack tip. Tearing propagation helps using dissipating energy of fillers within the polymer matrix, so as to gain more tear resistance property, that needs higher load to be applied to break the polymer matrix [26].

5. Conclusion

Reinforcement of A-2186 RTV Maxillofacial silicone with polyester powder (1%, 3%, and 5%) significantly improves all mechanical properties.

On the basis of the results obtained, it was concluded that tear strength, surface roughness, and tensile strength of the maxillofacial material used improved when the material was reinforced with polyester at certain concentrations. Furthermore, addition of polyester showed no significant effect on the hardness of the silicon elastomer but it was still within the acceptable clinical limit.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding this manuscript.

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