The effect of aging on tensile strength of two maxillofacial silicone materials before and after pigmentation

[1]Afeiaa Lateef Jassim and [2]Mohammed Abdul Hussain, PhD
[1,2]Department of Prosthodontic, College of Health & Medical Technology, Middle Technical University, Baghdad, Iraq.
Corresponding author: Afeiaa Lateef Jasim.
E-mail address: afeiaa2017@gmail.com

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Abstract
Background The approximate life span of a silicone maxillofacial prosthesis is as short as after 4-14 months of usage, then a new prosthesis should be fabricated. But now many researchers have been directed toward improvement of properties silicone elastomeric materials. The objective of this study is to evaluate the effect of aging on tensile strength of two types of silicone materials used in the maxillofacial prostheses (VST-30 and VST-06) after artificial weathering for 100, 200 and 300 hours, and then comparing between the two selected materials in terms of selected artificial weathering periods. **Material and methods** a sample of 160 specimens were prepared and divided into two main groups according to the types of elastomeric silicone (VST-30 and VST-06). Then each group subdivided into 8 divisions, (n=10). Two groups, one for clear and one pigmented as control groups before experimental weathering .While the experimental groups divided into clear and pigmented groups treated with artificial weathering for 100, 200 and 300 h. **Results** after different weathering cycles the results show that there was no significant difference in the tensile strength for VST-30 silicone material pigment before and after weathering. While there was a highly significant difference in the tensile strength for VST-06 pigmented silicone before and after weathering. Both VST-30 and VST-06 non-pigmented groups showed a highly significant change in the tensile strength after different weathering cycles. **Conclusions** the superior type for mechanical properties after difference cycles weathering was for VST-30 and incorporation of rayon flocking prevents the silicone materials from rapid degradation under artificial weathering and this may lead to increase in the service life of silicone prosthesis.

Keywords: Rayon flocking, VST-30 silicone, VST-06 silicone, room temperature, mechanical properties.

Introduction

Barnhart in 1960 firstly fabricated maxillofacial prosthesis and introduce silicone elastomer (Barnhart, 1960), since then become widely used as the material of choice for its chemical inertness, stability, ease of manipulation, biocompatibility and visual transparency which eases the pigmentation of silicone for simulating skin quality (Aziz et al, 2003, Rahman et al, 2019). Increasing numbers of maxillofacial deformity cases were reported in Iraq that are related to non-fatal damages caused by explosive devices, which now comprise 30% of all injuries (Lew et al, 2010, Shakir and Abdul-Ameer, 2018). Color degradation and mechanical properties are the most common reason for maxillofacial prostheses fabrication (Begum et al, 2011, Kantola, 2014). The mechanical properties of a silicone elastomer are dependent on many factors including the molecular weight of polymer chains, incorporation of filler and cross-link density (Bellamy et al, 2003, Nallaswamy, 2017). There are different types of pigments available on the market to stain facial prostheses which have different effects on material properties (Haug et al, 1999, Guiotti et al, 2016, Ding and Wolf, 2018). Pigments used for prostheses coloration are classified as extrinsic and intrinsic pigments. In comparison to extrinsic pigmentation, the intrinsic pigmentation method is the necessary color and translucency with less susceptible for handling and environmental status, while it is more probable to influence the mixture characteristics (Bellamy et al, 2003, Han et al, 2010). In order to transfer the material from a liquid to a rubber during processing, additives can incorporated into the compound such as colorants, antioxidants, fillers and cross-linking agents. Silicone resistance to heat and degradation during exposure to ultraviolet light is also related to the cross links between the long polymer chains (Zardawi, 2013, Smitha and Savitha, 2017).

Materials and methods

Materials used in this study were VST-30 Versiltal RTV silicone elastomer, VST-06 Platinum silicone elastomer and rayon flocking coloring powder (tan, flesh, and yellow) (Factor II Inc., Lakeside, USA). One hundred and sixty specimens were prepared and divided into two main groups according to the types of elastomeric silicone. The first group consisted of 80 specimens and prepared using VST-30 silicone, and the second consisted also of 80 specimens but prepared using VST-06 silicone. As the specimens under tensile test undergo plastic deformation, each main group divided into 8 subgroups, (n=10) and presented as follow, G1: clear silicone before weathering treatment and G2: pigmented silicone before weathering treatment as a control groups; while the experimental groups subdivided into G3: clear silicone after weathering treatment for 100 h; G4: pigmented silicone after weathering treatment for 100 h; G5: clear silicone after weathering treatment for 200 h; G6: pigmented silicone after weathering treatment for 200 h; and finally G7: clear silicone after weathering treatment for 300 h; and G8: pigmented silicone after weathering treatment for 300 h.

Molds preparation

Acrylic molds were prepared using laser cutting machine after being designed by (Auto CAD 2015) computer software (Yeh, 2014). The mold was composed of the three parts, template, base and cover lid of the acrylic mold.

Specimen treatment with pigments

In the current study, two types of silicone platinum RTV. VST-30 and VST-06 (Factor II Inc., USA) platinum catalyzed, vinyl terminated RTV silicone were used. According to the manufacturer›s instruction, the mixing ratio was of 10:1 base to catalyst by weighting for both non-pigment and pigment groups. In this study, two groups of specimens were fabricated. The first group was the non-pigmented groups consist of 80 specimens, which are fabricated by mixing 40g of silicone base and 4g of silicone catalyst without adding any pigments. The electronic digital balance was used for weighing the material and vacuum mixer was used for mixing the materials, with a speed of 360 rpm, and under mechanical vacuum mixer at pressure of (-10) bar. This was according to the pilot study which depended also on ISO standardization (ISO, 2011). The resulted homogenous silicone mixture poured into the molds and tightened by the screws and 4-G-clamps. The setting time of the experimental materials was according to manufacturers with 30 minutes for VST-30, and 16 hours for VST-06. The second group was the pigmented group which consists of also 80 specimens which was prepared by mixing of 39.35g/39.35g base to catalyst ratio and adding rayon flocking intrinsic pigmented mixture of powders of 0.3g (tan); 0.3g (flesh); and 0.05g (yellow) together. To achieve this mixing ratio for pigment groups, the following formula was applied: Base weight - pigment weight = Base weight (for the pigment groups). Base weight (for pigment groups)/ 10 = catalyst weight. The catalyst drops were dispensed in different place and not in the center only, to aid in gaining homogeneity rapidly while the glass beaker was on the digital scale (ISO, 2011, Hatamleh et al, 2011, Yatsuyanagi et al, 2001). The mixture was mixed under vacuum for 5 minute (Tukmachi and Moudhaffer, 2017). Pouring of the material was achieved at a controlled temperature of (25°C) and 50±10% RH as recommended by the manufacturer standards (Guiotti 2016: ASTM, 2013). Before closing the mold, the mold cover was coated with petroleum jelly oil and hex nuts are prepared and screws are inserted in each hole at the corner of the mold. Then silicone mixture is poured gradually to minimize the air bubbles. When pouring was finished, air bubbles on the surface were broken-up by using a fine needle. (Hatamleh et al, 2011, Zayed et al, 2014). After that the mold was stored away from light at room temperature of 25°C for 30 mins for VST-30 and for 16 hrs for VST-06 to complete the vulcanization of the RTV silicone and according to manufacturer›s instruction.

Figure 1: Vacuum Mixer.

During specimen preparation, the control of air bubbles by vacuum mixture was by mixing a little amount of› silicone, mixing the base and catalyst in one direction (Tukmachi and Moudhaffer, 2017, NEW), using of fine needle and applications of 1 kg weight on the mold covers and then wait for 1 min to get rid of the remaining air bubbles (Abdullah, 2016).

Finishing and Storage of samples
After complete set of the silicone, all specimens were removed carefully from the molds. Care was taken during removal of the specimens from the molds to mark the tensile strength without strain. Any flash and excess was removed with a scalpel and sharp surgical blade no 11, (Maxwell et al, 2003). Specimen that had visible defects was discarded, in addition checking thickness by measure of digital caliper (Zayed et al, 2014, Pinheiro et al, 2014, Al-Harbi et al, 2015). The Specimens were stored in a lightproof box in an air-conditioned room. During storage, temperature was 25°C, RH controlled to not excess 80%, the samples were stored in sealed bags and care was taken not to place specimens over each other (Liu et al, 2015, Brown, 2006) .

Aging procedure
The study experimental procedures were accomplished with artificial accelerated weathering using UV exposure. Weather-Ometer device (QUV) promote the same condition of outdoor weathering but in accelerated way, so many hours in device chamber simulate many days in outdoor weathering according to the site of study. The weathering standardization used in this study is ASTM (G154) which is the most popular accelerated weathering. According to cycle 7 of ASTM G154 the samples exposed to 25 cycles. The first 8 hours (light cycle) included irradiance of (340 nm) of (1.55 W/m2) and temperature of 60 (±3°C). The following 4 hours representing dark cycle included irradiance of (340 nm) of 1.55 W/m2 for 15 minutes with water spray system to induce thermal shock, and finally the specimens were exposed to artificial weathering tested after 100, 200 and 300 hrs and compared with that groups were tested before artificial weathering. The artificial weathering equivalent nearly to 3, 6 and 9 months of respectively clinical use taking into consideration the climatic conditions in Baghdad city (Al-Douri et al, 2016, Al-Riahi and Al-Kayssi, 1998).

Figure 2: Weather-Ometer device (QUV).

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Testing procedure for tensile strength property

Test was conducted according to (ISO, 2011). Dumbbell-shaped specimens were prepared. The thickness measurements were made at the center and at each end of the narrow portion of the test specimens (testing of the length) by using a Vernier caliper with digital read out. The average of the three measurements was taken. Tensile strength testing procedure was conducted using a computer controlled universal testing machine. The specimen was clamped by the jag grips of the machine symmetrically to distribute the tension equally over the cross-section. The speed of stretching of specimen was of 50 mm/min and the maximum stretching force at break was recorded by computer programmatic software. Any specimen that broke outside the narrow portion was discarded and a repeated test was conducted on an additional specimen, the final tensile strength was calculated from the maximum stretching force at break divided by the original cross sectional area of the specimen (width × thickness of the narrow portion) using the following formula:

Tensile strength=F/A where: F: the force recorded at fracture in Newton, A = W×T, W= the width of narrow portion of the specimen in millimeters and T= thickness of narrow portion of the specimen in millimeters.

Figure 3: Specimen under tensile test.

Statistical Analysis

The following data statistically analyzed using SPSS (V-20). Descriptive and Inferential data analysis were used to accept or rejected the statistical hypotheses. This included the one-way ANOVA (analysis of variance) for a quantitative dependent variable by a single factor independent variable and LSD test for examining the differences between each groups significant on P-value ($p \leq 0.05$) and confidence level of 95%.

Results

There was statistically a highly significant difference in the tensile strength in comparison between both types of silicone materials, the clear and the pigmented for both VST-06 and VST-30 and with the entire weathering treatment periods, P-value ($p \leq 0.01$) as shown in figures (4), (5) and tables (1), (2).

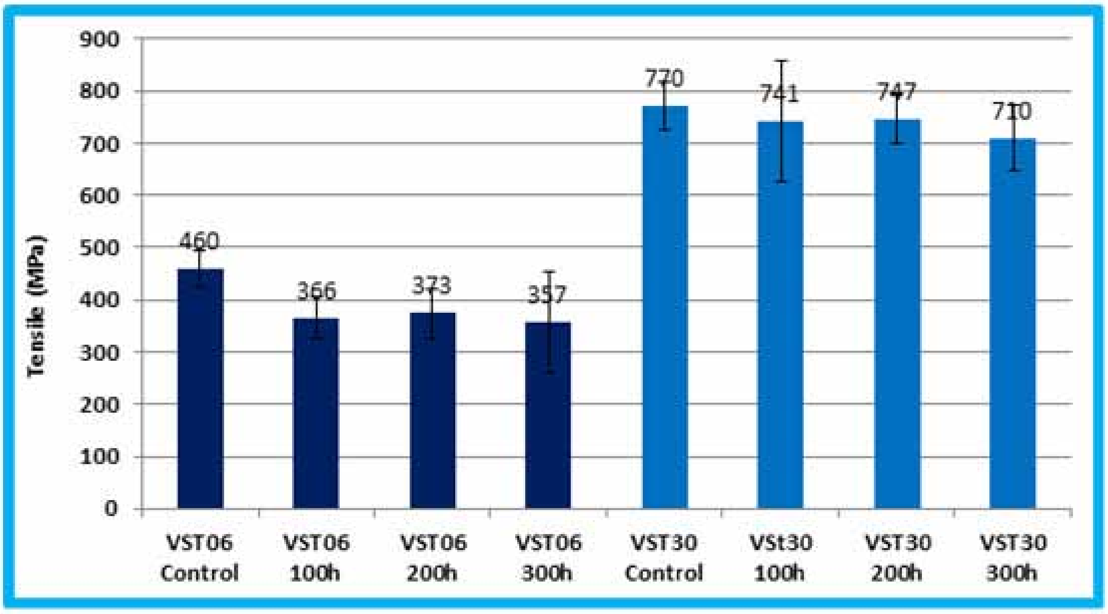

Figure 4: Mean values and standard deviation of tensile strength test for all study clear groups of VST-30 and VST-06.

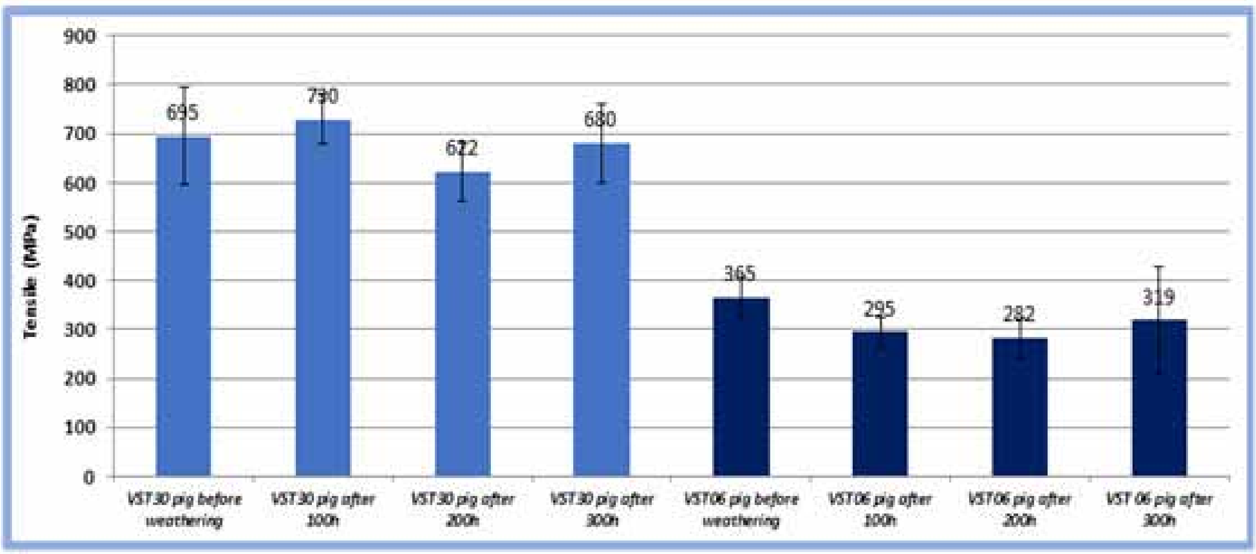

Figure 5: Mean values and standard deviation of tensile strength test for all study pigmented groups of VST-30 and VST-06.

Table 1: LSD of the tensile strength comparison between the two types of non-pigmented VST-30 and VST-06 silicones after weathering aging.

Grouping		Mean Difference (I-J)	*P*-value	Sig
VST-30 pig after 100h	VST-06pig after100h	434.903	.005	HS
VST-30 pig after 200h	VST-06 pig after 200h	339.571	.001	HS
VST-30 pig after 300h	VST-06pig after 300h	361.088	.003	HS

Table 2: LSD of the tensile strength comparison between the two types of pigmented VST-30 and VST-06 silicones after weathering aging.

Grouping		Mean Difference (I-J)	*P*-value	Sig
VST-30 clear after 100h	VST-06 clear after 100h	-2.46140	0. 01	HS
VST-30 clear after 200h	VST-06 clear after 200h	-3.4190	0. 01	HS
VST-30 clear after 300h	VST-06 clear after 300h	-2.98520	0. 01	HS

Discussion

The mechanical properties of clear silicones may only reported by the manufacturers without pigmented fillers or additives and this is seem not in a real representation of silicones at clinical performance when it used for extra-oral prosthesis. In the current study the mean value of tensile property in comparison with the control group. The increase in tensile strength mean value after rayon flocking incorporation may be due to stress transitions from the weaker resin matrix to the much stronger fibers and the effective restraining of the matrix by fibers, which led to obstructing of the growing crack (Abdullah, 2016) . In the current study, the pigmented specimens were exposed to 100, 200 and 300 hours of artificial weathering equal nearly to 3, 6 and 9 months of clinical use, taking into consideration the climatic conditions in Baghdad city (Al-Douri et al, 2016, Al-Riahi and Al-Kayssi, 1998). The reinforcement depends to a large extent on the polymer properties, filler characteristics particle size or specific surface area structure and surface activity, filler loading ratio or percentage and processing conditions (Brown, 2006, Al-Douri et al, 2016). The results from this study indicate that incorporation of rayon flocking pigmented powders into a maxillofacial silicone may improve the tensile strength, this can be explained by the ability of the polymer to dissipate the strain energy near the tip of the growing crack. It also could be explained by two other theories. The first is the decrement in the tensile strength which may be due to photo oxidative effect of the artificial weathering. The free radical formation and reaction of these radicals with each other led to further cross linking, this lead to polymer structural modification and changing in the molecular weight distribution and the producing of volatile degradation products (Guiotti et al, 2016, Pinheiro et al, 2014). The second is with the time and accelerated UV light. The cross-linking of polymers will continue and increase, the associated with the more volatile decomposing from catalyst produces denser elastomer. Silicone when exposed to high energy of irradiation undergo cross linking, this cross linking was too high level that resulted in degradation of silicone in physical and mechanical properties and become brittle and inelastic and easily deformed with lower forces (Hatamleh et al, 2011). Pinheiro et al. believed that the elevated temperature reduces the strength of the polymers and increases the stiffness (Pinheiro et al, 2014). The results were in disagreement with Al-Harbi et al, 2015, who found that the tensile strength is not affected by outdoor weathering on A-2186 maxillofacial silicone and this may be due to different filler and different weathering environment (Al-Harbi et al, 2015). The results also in accordance with Zardawi who studied the effect of different natural condition and artificial weathering condition on mechanical properties of silicone polymer (SP) and 3D starch printed infiltrated silicone polymer (SPIS) (Zardawi, 2013). The result showed significant decrease in tensile strength after artificial weathering for both materials. The results of this study are partially agreed with Hatamleh et al. who found that there was little degradation with tensile strength of TechSil S25 maxillofacial silicone after 360 hours of artificial daylight aging and severe degradation with mixed artificial aging and sebum storage for 360 hrs (Hatamleh et al, 2011).This partially agreement could be due to different artificial aging cycle and presence of the sebum. Results are in agreement with Haug et al. who found that there was a non-significant difference in tensile strength with the addition of flocking to Silicone A-2186 or Silastic 4-4210 silicones (Haug et al, 1999) with VST-30 . On the other hand, the results disagree with (Haug et al, 1999) because the tensile strength of a silicone was decreased significantly by the addition of pigment with VST-06.

Conclusions It has been concluded that the superior type of silicone for the tensile strength mechanical property after difference cycles weathering was VST-30. Also the incorporation of rayon flocking coloring powders may tend to prevent the silicone materials from rapid degradation under artificial weathering cycles and may result in an increase in the service life of maxillofacial prosthesis fabricated using this silicone.

Conflict of interest

We are the author’s (Afeiaa lateef Jassim, and Assist. Prof. Dr. Mohammed Abdul Hussein) state that the manuscript for this paper is original, and it has not been published previously and it is part of my MSc. dissertation and it is not under consideration for publication elsewhere, and that the final version has been seen and approved by all authors.

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