ORIGINAL RESEARCH

Influence of Weather on Hardness and Surface Roughness of Maxillofacial Elastomeric Materials

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Abstract

Aims: The purpose of this study was to assess the influence of hot and dry weather on the hardness and surface roughness of four different maxillofacial silicone elastomeric materials (MFSEM) including two room-temperature vulcanized (RTV) and two high-temperature vulcanized (HTV) materials.

Materials and methods: Eighty test specimens were fabricated according to the manufacturer's instructions into rectangular test specimens. The hardness and surface roughness were tested, after 6 months of exposure to natural hot and dry weather. The hardness was measured through the International Rubber Hardness Degree (IRHD) scale using an automated hardness tester. The surface roughness was measured using a novel 3D optical noncontact technique using a combination of a light sectioning microscope and a computer vision system. Statistical Package for Social Sciences software SPSS/version 24 was used for analysis and a comparison between two independent variables was done using an independent *t* test, while more than two variables were analyzed, *F* test (ANOVA) to be used followed by a *post hoc* test to determine the level of significance between every two groups.

Results: The hot and dry weather statistically influenced the hardness and surface roughness of MFSEM. Cosmesil M-511 showed the least hardness in test groups while A-2000 showed the hardest material ($p < 0.05$). A-2000 showed significant changes from rough in case of nonweathered to become smoother in weather followed by A-2186 ($p < 0.05$). Cosmesil M-511 showed the roughest material.

Conclusion: Cosmesil M-511 showed the least hard MFSEM after outdoor weathering while A-2000, the highest and least material showed hardness and surface roughness, respectively.

Clinical implication: A-2000 had a high IRHD scale hardness. This makes this material more suitable for the replacement of ear and nose defects. Cosmesil M-511 is soft and easily adaptable material that makes the material more appropriate for the replacement of small facial defect with undercut area to be easily inserted and removed. Whilst A-2000 is smoother and finer in test specimens after weathering, Cosmesil M-511 became rougher after weathering.

Keywords: A-2000, A-2186, Cosmesil M-511, Hardness, Maxillofacial elastomeric, Surface roughness, TechSil S-25.

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Introduction

Diversity of materials can be used in maxillofacial prosthetic rehabilitation. Examples of these materials include polymethyl methacrylate, polyurethanes, polyvinyl chloride, chlorinated polyethylene, and maxillofacial silicones elastomers materials (MFSEM). Maxillofacial silicones elastomers materials is the most commonly used material to construct maxillofacial prostheses that are used to replace the congenital and acquired facial missing parts due to its texture, biocompatibility, strength, durability, simplicity in handling and fabrication, coloring, tear and tensile strength, and comfort of the patients.[1–5]

According to the vulcanization reaction, the silicone elastomers can be divided into two distinct types; high-temperature vulcanizing (HTV) and room-temperature vulcanizing (RTV) silicones.[6] Different types of silicone elastomers have a different range of surface characteristics and mechanical properties. It was reported that HTV silicones have superior advantages regarding the physical properties, thermal stability, and color stability comparing to RTV.[7] In disagreement with that, one study have reported superior properties of the RTV silicones compared to other different materials including HTV regarding color stability.[8] One study found the results of evaluation of mechanical properties of TechSil S25 as a HTV silicone after exposure to weather and solar radiation is a promising,[9] while other study had a contradictory report.[10]

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However, there is agreement that both types of the MFSEM are subjected to degradation in the mechanical and physical properties and changes in the color and surface smoothness of the materials.[11–13] This mainly happened due to exposure to solar radiation, humidity, air pollution, and prostheses maintenance materials.[11,14–17] This degradation can be faster or less depending on geographic area, climate changes, and the materials used in maintenance of the prosthesis itself.[18–20]

The roughness of a material is a measure of the fine irregularities of the surface texture in the materials. Surface roughness average (R_a) is the deviation of the surface valleys and peaks in microinches or micrometers; the surface is considered rough surface when the deviations are great; if the deviation was minor, the surface is considered smooth. The surface roughness of a material can be measured by different methods such as optical techniques, surface profilometer, and scanning electron microscopy.[20–22]

Hardness, as a mechanical property, is defined as resistance to penetration or permanent deformation. Deformation or penetration of materials occurred as a result of many causes such as scratching, indentation, cutting, mechanical wear, and bending. There are many factors that should be considered when measuring the hardness of such material, such as, the type, size and shape, surface condition, degree of flatness, homogeneity, and work environment. Hardness is one of the most widely measured properties used to characterize rubber-base materials. There are two different ways to measure the hardness of rubber materials; International Rubber Hardness Degree (IRHD) scale and shore A scale.[23,24]

Selection of proper material depends on the sustainability of this material regarding surface characters in different weathering effects. Various studies have been conducted to investigate the influence of weather on the physical and mechanical properties of MFSEM.[18,19,25] However, to the best of the author's knowledge, no studies were conducted to evaluate the hardness and surface roughness of MFSEM in the hot and dry weather with high UV scales. The present study aimed to compare the influence of weather of Jouf Province, Saudi Arabia, which characterized hot, dry, and high solar ultraviolet (UV) scales on the hardness and surface roughness of four types of MFSEM, including two room-temperature vulcanized (RTV) (A-2186 and A-2000) and two heat-temperature vulcanized (HTV) (Cosmosil M-511 and TechSil S-25). It is assumed that the high UV scale, hot, and dry weather have no adverse effect on the hardness and surface roughness of MFSEM (the null hypothesis H_0). The results of the present study (H_1) were compared with that of the null hypothesis (H_0).

Materials and Methods

Selection and Preparation of Specimens

In the present study, specimens of four MFSEM included two RTV (A-2186 and A-2000) and two HTV (Cosmosil M-511 and TechSil S-25) as shown in Table 1. An 80 rectangular-shaped specimens were prepared, 20 for each material, (20 mm × 15 mm × 10 mm) according to ASTM D1415 – 18 standards using 8 pieces stainless steel molds that have been fabricated through cutting of stainless steel–steel blade to provide a smooth surface for each specimen.[26] The test specimens were prepared according to the manufacturer's instructions and poured randomly in the molds along 10–12 working days. The 80 specimens test materials were labeled and 40 of them, 10 for each material, were stored in a dehumidifier (Che Scientific Co.; Kwai Chung, Hong Kong) at 24°C and 50% relative humidity for 6 months + 10–12 days to be tested as a control group.[13,27] The other 40 labeled specimens were exposed to the natural weather of Jouf Province, Saudi Arabia, for the same 6 months + 10–12 days to be tested as study test specimens. The exposure of specimens was done by suspending them from racks of woods with stainless steel ligature wire (Bego; Bremen, Germany) that placed on the rooftop of the College of Dentistry, Jouf University, from May 2019 to October 2019.[21,28] Before testing the change in properties, the test specimens were removed, washed for 10 minutes in distilled water (Hilwa; Hilwa Water Factory, Dumah Al Jandal, Saudi Arabia), and finally dried for to be examined.

Table 1: The elastomeric materials included in the study

Material	*Manufacturer*	*Type of curing*	*Processing parameters*	*Ratio*
A-2186	Factor II Inc (Lakeside, USA)	RTV	Polymerized at room temperature for 24 hours	10:1
A-2000	Factor II Inc (Lakeside, USA)	RTV	Polymerized at room temperature for 72 hours	1:1
Cosmesil M-511	Principality Medical LTD (Newport South Wales, UK)	HTV	Processed for 2 hours at 100°C in dry heat oven	10:1
TechSil S-25	Technovent Ltd (Leeds, UK)	HTV	Processed for 2 hours at 100°C	9:1

Surface Roughness Measurement

The surface roughness has been measured in three-dimensions (3D) optical noncontact technique using a combination of a light sectioning microscope and a computer vision system.[29,30] Specimens were photographed using a portable digital microscope with a built-in camera of 5.0 MP image sensor (Bmp-350; Catchbest Vision Technology Co., Beijing, China) linked through universal serial bus (USB) with an International Business Machines personal computer (IBM pc) (Dell-pc; CPU Intel ® Core ™ i7 4500U, 1.80-2.4 GHz processor, 500 GB hard disk, 8 GB RAM, Windows 8.1 Ultimate Version Service Pack, China). The microscope provides a magnification of 20–300×. The magnification set to 150× for the captured photos to all test specimens. Images were stored with a resolution of 1280 × 1024 pixels per image. Digital microscope images were cropped to 350 × 400 pixels using Microsoft office picture manager (Microsoft Picture Manager 2017; Microsoft Corporation, Redmond, United States) to specify/standardize area of roughness measurement. The images were examined by WSxM software (WSxM v4.0 Beta 9.3; Free Scanning Probe Microscopy Software)[30] while all parameters were conveyed in pixels and the pixels changed into units in (μm) by WSxM system standardization. The WSxM system standardization was prepared by matching the ruler in the table of the digital microscope with the scale generated by the WSxM software so a 3D image of the surface profile of the specimen was produced. Five 3D images were gathered for each specimen, randomly in the central area and on the sides. WSxM software then used to estimate the irregularities of the surface (R_a) stated in the form of (μm).

Hardness Measurement

The hardness test was done through International Rubber Hardness Degree (IRHD) scale using an automated Wallace Cogenix Dead Load Hardness tester (H14; H.W. Wallace and Co Limited, Surrey, England), according to the method described by BS ISO 48.[31] The test machine started automatically by pressing the start button. The keys on the front panel were head up and down until the test specimen was adequately located and secured. Once the start key was pressed, the annular foot with a fitting sphere-shape indenter of 2.5 mm in diameter descended to the center of the test specimen

Table 2: Monthly climatic data and UV index scores during outdoor weathering

Month 2019	*Temperature H/L*	*Rainfall (mm)/ days (n)*	*Wind speed (Kmph)/Gust (Kmph)*	*Pressure (mb)*	*Humidity (%)*	*Sun hours/days*	*UV index scale*
May	37.6/21.8	4/2	16/22.8	1009.5	13	361/27	9
June	40.8/26.4	5.2/3	15.5/22.7	1006.4	15	367.5/27	8
July	40.9/26.8	0/0	14.8/23.4	1003.9	16	387.5/31	9
August	41.1/26.8	0/0	15.6/24.4	1004.8	17	386/31	9
September	40.2/25.3	0/0	12.9/21.7	1007.6	18	300/30	8
October	34/21.6	6.8/6	11.9/19.3	1012	27	299.5/25	6

H/L, maximum temperature/minimum temperature; *n*, number; Kmph, kilometer per hour; mb, millibars
UV index scale, 0–2 low, 3–7 moderate, 8+ high to extreme

with a primary load of 0.3 N ($L_0 = 0.3$ N) to find its datum point. After 5 seconds, in-line with the testing standards, the force was increased to 5.4 N ($L_1 = 5.4$ N) and applied for a further 30 seconds. At this point, the instrument identifies the indenter position and the hardness value is automatically frozen and displayed clearly on the screen. The scale of degrees being so established between 0 and 100 chosen at the 0 represents a material having an elastic modulus of zero, and 100 represents a material of infinite elastic modulus.

Statistical Analysis

Data were fed to the computer using Statistical Package for Social Sciences software SPSS/version 24 (IBM, Chicago, IL, United States). Quantitative data were described using mean and standard deviation for normally distributed data. For normally distributed data, a comparison between two independent variables was done using an independent *t* test, while more than two variables were analyzed, *F* test (ANOVA) to be used followed by a *post hoc* test to determine the level of significance between every two groups.

Results

The climate of Jouf Province is a hot (average 40.8/26.4) and dry (average humidity 17.6%) weather with very low rainfall (average 3.2 mm/6 months) in summer with a high UV scale (average 8.9 indexes) as shown in Table 2.

The comparison between the hardness of the nonweathered and weathered test specimens is shown in Table 3 and Figure 1. Within group, all the test specimens showed a significant increase in the IRHD scale due to hot and dry weather ($p < 0.05$) except Cosmesil M-511 which showed a significant decrease in the IRHD scale (21.00 ± 0.79 for control and 16.88 ± 0.95 for test specimens, $p < 0.05$). Cosmesil M-511 also showed the least hard material among groups (16.88 ± 0.95) while A-2000 showed the hardest one among the groups after weathering (37.34 ± 2.36, $p < 0.05$).

Table 4 and Figure 2 show the comparison between the surface roughness (R_a) of the test specimens within and among each test specimen. Within the same group, A-2000 was the only test specimen which shows a significant decline in the surface roughness (for control 0.23 ± 0.08, and 0.09 ± 0.05 for test materials, $p < 0.05$) while others showed insignificant changes in their surface roughness ($p > 0.05$). Among groups, A-2000 also was the specimen with the least rough surface comparing the other test specimens ($p < 0.05$), while Cosmesil M-511 test specimen was the roughest materials ($p < 0.05$).

Discussion

The surface roughness as a surface property is a good indicator of mechanical performance of elastomeric materials. An irregularity in the surface might produce nucleation sites for cracks, corrosion, and bacterial contamination. The surface roughness was evaluated using a novel optical noncontact technique for 3D characterization using a combination of a light sectioning microscope and a computer vision system. This optical approach technique simplifies the assessment of roughness compared to electron microscope and profilometer approaches in terms of being noncontact, fast, and cheap.[22,29,30] All test specimens, except TechSil S-25, were affected by the weather, either by increasing or decreasing value, and the null hypothesis was rejected except for TechSil S-25. A-2000 became smoother and finer in test specimens after weathering. This can be explained by the fact of continuous polymerization which promotes further arrangement and supplement of polymer

Table 3: Comparison between hardness of different studied materials in both weathered and nonweathered

Group materials	*Nonweathered*	*Weathered*	*t test* $P^{\$}$ *value*
1. A-2186			
Range	23.9–25.3	30.4–35	6.25 (*t* test)
Mean ± S.D.	24.46 ± 0.54	33.08 ± 1.98	0.001*
2. A-2000			
Range	25.7–27.1	33.2–39.1	5.68
Mean ± S.D.	26.30 ± 0.51	37.34 ± 2.36	0.001*
3. Cosmesil M-511			
Range	19.7–21.8	16.1–18.4	5.71
Mean ± S.D.	21.00 ± 0.79	16.88 ± 0.95	0.001*
4. TechSil S-25			
Range	25.3–26.1	31.2–35.2	4.96
Mean ± S.D.	25.74 ± 0.34	33.48 ± 1.49	0.0023*
ANOVA	25.65	21.6	
p value	0.001*	0.001*	
*P*1	0.0003*	0.0074*	
*P*2	0.0001*	0.0001*	
*P*3	0.001*	0.3639 N.S.	
*P*4	0.0001*	0.0001*	
*P*5	0.038*	0.0074*	
*P*6	0.0001*	0.0001*	

$P^{\$}$ comparison between nonweather and weathered in the same group.
*P*1 comparison between groups I and II
*P*2 comparison between groups I and III
*P*3 comparison between groups I and IV
*P*4 comparison between groups II and III
*P*5 comparison between groups II and IV
*P*6 comparison between groups III and IV

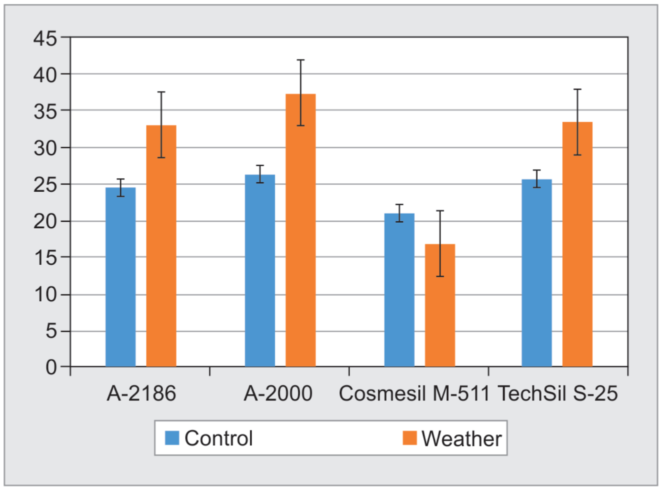

Fig. 1: Comparison between hardness of different studied materials in both weathered and nonweathered

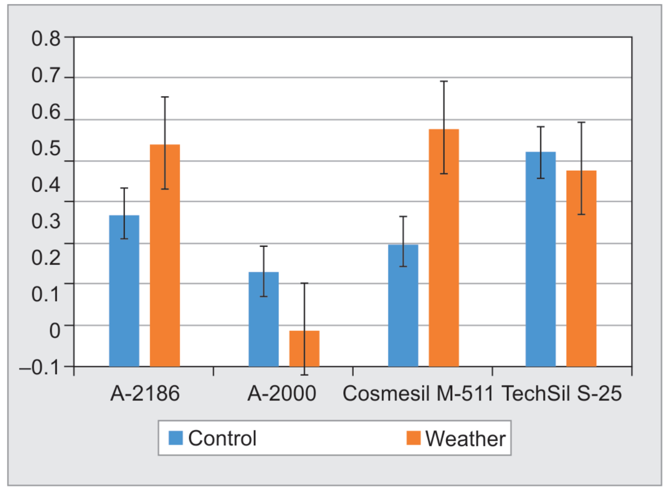

Fig. 2: Comparison between surface roughness in different studied materials in both weathered and nonweathered

Table 4: Comparison between surface roughness in different studied materials in both weathered and nonweathered

				t test
	Group materials	*Nonweathered*	*Weathered*	$P^{\$}$ *value*
1	A-2186			
	Range	0.318–0.537	0.447–0.765	2.07
	Mean ± S.D.	0.37 ± 0.09	0.54 ± 0.13	0.027*
2	A-2000			
	Range	0.121–0.314	0.013–0.122	5.21
	Mean ± S.D.	0.23 ± 0.08	0.09 ± 0.05	0.006*
3	Cosmesil M-511			
	Range	0.299–0.311	0.503–0.689	4.98
	Mean ± S.D.	0.30 ± 0.001	0.58 ± 0.10	0.003*
4	TechSil S-25			
	Range	0.319–0.813	0.307–0.704	0.968
	Mean ± S.D.	0.52 ± 0.23	0.48 ± 0.14	0.380 N.S.
	ANOVA	20.6	14.85	
	P value	0.001*	0.003*	
	*P*1	0.016*	0.0001*	
	*P*2	0.073 N.S.	0.28 N.S.	
	*P*3	0.1062 N.S.	0.286 N.S.	
	*P*4	0.0376*	0.0001*	
	*P*5	0.0143*	0.0002*	
	*P*6	0.0343*	0.1267 N.S.	

$P^{\$}$ comparison between nonweather and weathered in the same group.
*P*1 comparison between groups I and II
*P*2 comparison between groups I and III
*P*3 comparison between groups I and IV
*P*4 comparison between groups II and III
*P*5 comparison between groups II and IV
*P*6 comparison between groups III and IV

causing the surface to become smoother and finer. This makes this material more suitable for facial defects including missing parts of the oral cavity to decrease the plaque deposition upon using. On the contrary of A-2000, Cosmesil M-511 became rougher after weathering. This can be explained by an increase of the fillers added to material during manufacturing. Comparing this study, up to the author's knowledge, there was no conducted study in the effect of natural weathering on the surface roughness on test specimens used of this study to compare with. According to this study, A-2000 considered better option regard to increasing hardness and surface smoothness, so it can be used for larger defects and smooth areas of the facial surface. The clinician needs to decide which suitable materials he needs according to each case requirement and type of his/her country weather.

The hardness of elastomeric materials can be measured through shore A hardness test and International Rubber Hardness Degree (IRHD) scale. Using touch automated machine provides advantages of accuracy, reproducibility, and consistency results with easy access to the samples and less need for operator hands technique for measurement of the hardness compared with the operator hand technique that used in case of shore A hardness test.[32] Maxillofacial silicone elastomers should have a suitable hardness ranging from 25 to 35 to provide good resemblance of skin tissue in the facial defective side.[25,33] All the silicone elastomer specimens examined in the present study became harder after subjecting to hot and dry weather and the null hypothesis (H_0), accordingly, was rejected. A-2000 had the highest IRHD hardness scale. This makes this material more suitable for replacement of ear and nose defects. Cosmesil M-511 also showed the least hard material among groups (16.88 ± 0.95) which make it soft and easily adaptable materials which make the material more appropriate for replacement of small facial defect with undercut area, to be easily inserted and removed. The result regarding the A-2000 was consistent with the result done on different MFEM, including A-2000 after weathering in Indian and Mediterranean climate.[18] The result regard to Cosmesil M-511 was comparable to that study conducted on the exploration of the solar effect of different kinds of elastomeric materials, including Cosmesil M-511.[10,25,34] The increase in the hardness is explained by continuous polymerization, as a function of the aging process, and evaporation of the ingredients in the polymer.

The results obtained from this study would be beneficial to the maxillofacial prosthodontist to make adequate decision in the selection of proper silicone regarding the effect of environment. It helps the maxillofacial prosthodontists to fabricate a long-lasting stable maxillofacial prosthesis, avoiding remaking of the prostheses, wasting of the material, and time of fabrication.

In the present study, the effect of weather of hot, dry, and high UV was studied. No single factors of them were identified exactly if it was the cause of changes in surface roughness and hardness of test materials. This can be considered a limitation. Other more limitation of this study is the human factors, which was ignored also in the sustainability of the materials. Future studies are suggested to involve the effect of these factors over the same and longer period of time may be needed

Conclusion

Within the limitations of this *in vitro* study, it can be concluded:

- A-2000 maxillofacial elastomeric material shows an increase in the hardness and smoothest after weathering indicating adequacy of these materials for replacement of small facial defects, such as, nose and ear.
- Cosmosil M-511 is soft and easily adaptable materials after weathering compared with other test materials recommending its use for replacement of facial defects with deep undercuts.

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