Original Paper

Effect of tulle on the mechanical properties of a maxillofacial silicone elastomer

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The purpose of this research was to investigate if physical properties could be improved by incorporating a tulle reinforcement material into a maxillofacial silicone elastomer. A-2186 silicone elastomer was used in this study. The study group consisted of 20 elastomer specimens incorporated with tulle and fabricated in dumbbell-shaped silicone patterns using ASTM D412 and D624 standards. The control group consisted of 20 elastomer specimens fabricated without tulle. Tensile strength, ultimate elongation, and tear strength of all specimens were measured and analyzed. Statistical analyses were performed using Mann−Whitney U test with a statistical significance at 95% confidence level. It was found that the tensile and tear strengths of tulle-incorporated maxillofacial silicone elastomer were higher than those without tulle incorporation ($p<0.05$). Therefore, findings of this study suggested that tulle successfully reinforced a maxillofacial silicone elastomer by providing it with better mechanical properties and augmented strength — especially for the delicate edges of maxillofacial prostheses.

Key words: Color stability, Aging, Spectrophotometer

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INTRODUCTION

Silicone elastomers are used to fabricate maxillofacial prostheses to replace missing facial parts which have been lost due to ablative surgery, congenital deformity, or trauma. Against this background, maxillofacial prostheses are intended to improve esthetics, restore and maintain the health of the tissue bed, and allow patients to return to society in the best possible condition and remain functioning members that lead a normal life[1-4].

The mean lifetime of a facial prosthesis made of silicone elastomer has been accepted as 6−14 months[5-8]. Replacements are commonly done due to color fade or wear of the silicone material, especially at the edges[5,7,9,10]. Physical and mechanical properties of silicone elastomer are dependent on the degree of crosslinking and the type and concentration of fillers in the elastomer network. As for the degree of crosslinking, it depends on the nature and concentration of the thermal initiator, the fillers, and the additives, as well as cure temperature and polymerization time. All these factors affect the overall strength and service life of the silicone material[11-13].

In a bid to improve the physical properties of maxillofacial materials, elastomers have been modified with additives like coloring agents and reinforced with glass fibers, silica fibers, ceramic whiskers, cellulose fibers, or carbon block silica[14-20]. However, the addition of excessive amounts of fillers, organic or inorganic solids can be detrimental in that they degrade the physical properties of the silicone resin composite[21].

Recently, in a published report on improving the edge strength of facial prostheses[22], the reinforcement material used was tulle. Currently, tulle is ubiquitously used in theaters and operas to fabricate artificial beards and moustaches, whereby hair is sewn on flesh-toned, nylon tulle and the latter attached on the skin with prosthetic adhesives. Nonetheless, in a bid to increase the tear resistance of the margin of maxillofacial prostheses, tulle was incorporated in silicone elastomer in a recent research[22]. Tulle was chosen as the candidate material because its inherent flexibility would not cause any damage to the elastic behavior of the silicone material, thus preventing the latter from tearing at the edges[22,23]. However; no research has been done to investigate and evaluate the strength of silicone elastomers reinforced with tulle. Therefore, the purpose of this study was to compare the physical properties of tulle-integrated silicone elastomer against those of a normal silicone elastomer.

MATERIALS AND METHODS

Materials used

A-2186 maxillofacial silicone elastomer (Factor II Inc., Lakeside, AZ, USA) was used for this study. For reinforcement, mesh type tulle (No. 01 − Fine front and moustache lace, Nylon Art. 2429, Kryolan GmbH, Berlin, Germany) was selected as the experimental material for investigation. This material was purchased in stores related to film and cinema industries.

Specimen groups and preparation

This study comprised two specimen groups: study group *versus* control group. The study group consisted of 20 elastomer specimens in which tulle was embedded. The control group consisted of 20 elastomer specimens fabricated without tulle. Ten specimens from each group were prepared in a dumbbell-shaped form, while the other 10 specimens in trouser-shaped form for the tensile and elongation tests.

Rubber patterns were machined to adhere to the conditions of tensile and tear test methods set out in ASTM D412[24] and D624[25] respectively (Figs. 1A and 1B). Rubber patterns were invested in a dental stone (Glass Stone 3000 Type V, Dentsply International Inc., York, PA, USA) in metal flasks (Technovent Ltd., Leeds, UK) for constructing the molds. After the stone set, the flasks were opened and the

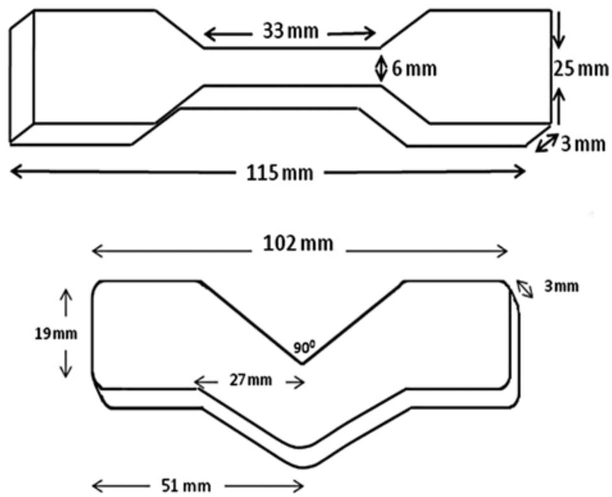

Fig. 1 (A) Dumbbell-shaped specimen prepared according to ASTM D412 specification; (B) Right-angled (C-shaped) specimen prepared according to ASTM D624 specification.

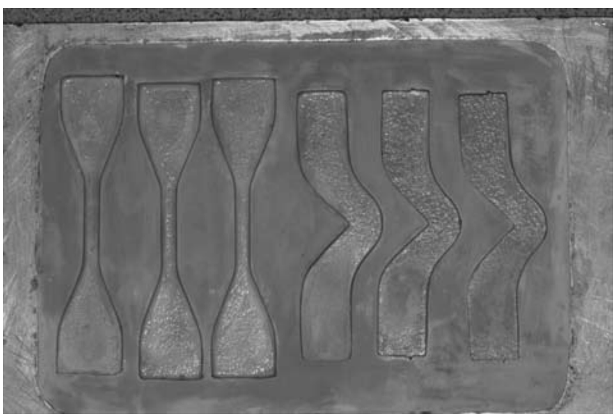

Fig. 2 Test specimens.

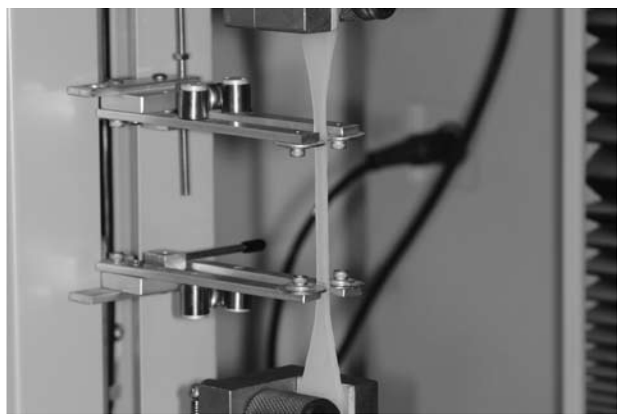

Fig. 4 Elongation test of specimens.

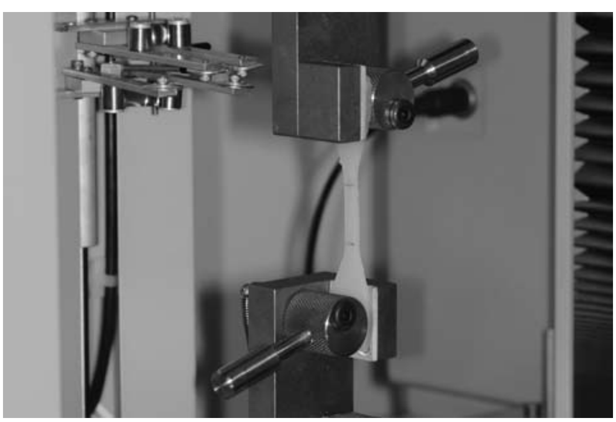

Fig. 3 Tensile strength test of specimens.

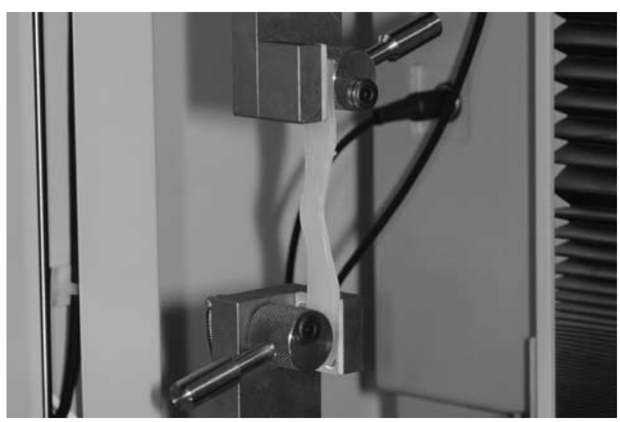

Fig. 5 Tear strength test of specimens.

patterns were removed (Fig. 2).

A-2186 was mixed with its hardener at a ratio of 10:1 using an electronic balance (Type AX120, Shimadzu Corp., Japan). The mixture was mixed in a vacuum mixer (Whip Mix Corp., Louisville, KY, USA) for 20 seconds. The mixture was loaded into 30-cc disposable plastic syringes (Factor II Inc), whereby care was taken not to trap air in the material during syringe loading. The material was then injected into the molds, and one layer of tulle (with the same dimensions as the molds) was embedded into the elastomer. Owing to the meshed structure of tulle, mechanical integration occurred between tulle and the silicone material. The specimens were polymerized using a dry heat oven for 1 hour at 100°C. After polymerization, the molds were separated and a surgical blade was used to remove excess material. All specimens were visually inspected to ensure that they were free of defects.

Mechanical tests

Tensile tests were carried out following ASTM D412 standard with dumbbell-shaped specimens. Tensile strength and elongation at break (in percent) were measured using a universal testing machine (M500-25kN, Testometric Co. Ltd., Lancashire, UK). The latter was equipped with an extensometer (DE-A extensometer, Testometric Co. Ltd., Lancashire, UK) and fitted with a 100 kg load cell. Tensile tests were carried out at a crosshead speed of 500 mm/min (Fig. 3). After the specimens were broken, failed specimens were evaluated to determine if failure was correlated with defects in the specimens. For the elongation test, the extensometer grips were set apart at a distance of 25 mm (Fig. 4). Tear tests were performed according to ASTM D624 standard with trouser-shaped specimens. Silicone tear specimens were tested at a crosshead speed of 51 mm/min, and then tear strengths were measured (Fig. 5). Failed specimens were evaluated if failure was correlated with defects in the specimens.

Statistical analysis

All statistical analyses were performed using a SPSS software package (Statistical Package for Social Sciences, version 13.0 for Windows, SPSS Inc, Chicago, IL, USA). Descriptive statistics (means, standard deviations, and coefficients of variation) were determined for all the groups. Mann−Whitney U test was used to determine significant differences in the groups' results. Statistical significance was determined at 95% confidence level, where P values less than 0.05 were considered to be statistically significant in all tests.

RESULTS

Table 1 presents the Mann−Whitney U test results of tensile and tear strengths and elongation at break (in percent) for both study and control groups. A statistically significant difference was observed in the tensile strengths of silicone elastomers with and without tulle incorporation ($P<0.05$). The study group was found to have significantly higher tensile strength than the control group. Statistically significant difference ($P<0.05$) was also observed in tear strength, whereby the study group was found to have significantly higher resistance to tearing than the control group. Similarly, statistically significant difference ($P<0.05$) was found for the elongation

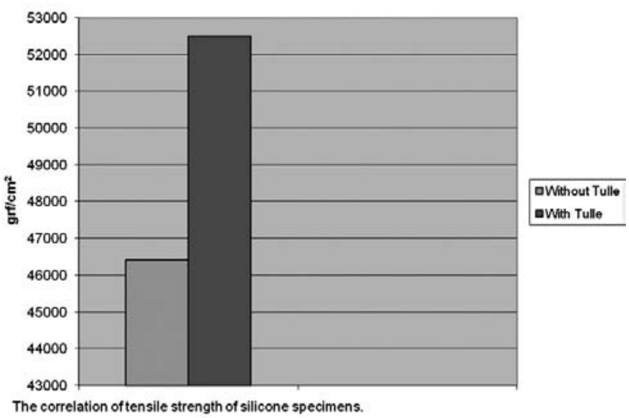

Fig. 6 Correlation of tensile strengths of silicone specimens.

Table 1 Means and standard deviations obtained with Mann−Whitney U test

	Control Group (without tulle) Mean±SD	Study Group (with tulle) Mean±SD	Mann−Whitney U Test Z	p
Tensile strength (gf/cm²)	46409.55±5361.73	52505.17±3804.21	−2.534	0.01
Tear strength (gf/cm²)	281.66± 37.73	449.48± 46.5	−3.780	0.0001
Elongation (%)	371 ± 34.79	297 ± 41.65	−3.072	0.002

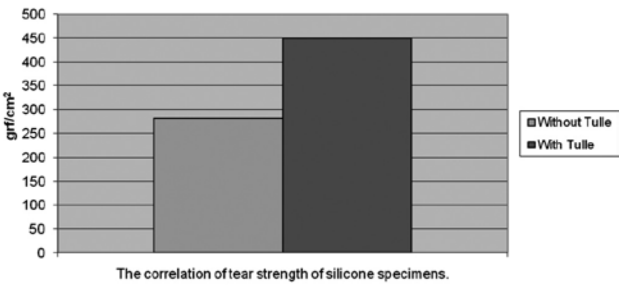

Fig. 7 Correlation of tear strengths of silicone specimens.

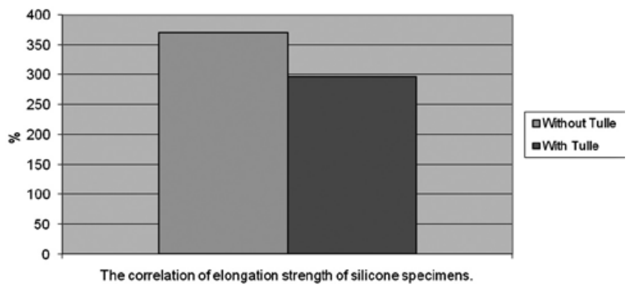

Fig. 8 Correlation of elongation values (%) of silicone specimens.

results, whereby the study group exhibited significantly a lower percentage of elongation at break than the control group. The correlations of all the mechanical test results are demonstrated in Figs. 6, 7, and 8.

DISCUSSION

Fabrication of a maxillofacial prosthesis is a time-consuming, labor-intensive, and costly procedure. However, two common causes lead to maxillofacial prostheses requiring frequent replacement — namely color fade and physical properties' degradation of the materials used[7,5,8]. On the other hand, in practical clinical settings, patients have an unrealistically high expectation of their prosthesis longevity[9]. Currently, the most widely used material for maxillofacial prostheses is silicone elastomer; but still, this material is far from ideal[12,13,16,17-19,21]. When a maxillofacial prosthesis degrades, two aspects are affected: mass and color. In published literature to date, most of the researches focus on degradation related with color change[5,7,8,10,20,21], with little research on the mechanical features.

For a facial prosthesis, degradation generally begins at the edges that need to be finished as thin as possible. These thin edges easily deform and tear with the effects of medical adhesives, cleaners, and body fluids. With silicone elastomers, one major drawback is their low tear resistance[22]. To date, no maxillofacial materials possess the resistance that is sufficient to withstand the tearing and rupturing effects these edges are frequently exposed and subjected to. In view of the crucial need for sufficient tear resistance, some researches have experimented with additives such as silica powder, short glass fibers, and natural fibers to improve the mechanical properties[12-19].

In the same vein, this study set out to investigate if embedding textured materials like tulle or mesh would serve as an effective reinforcement material against tear. It is noteworthy that in researches related with the reinforcement of mechanical properties of silicone materials used in maxillofacial prostheses, none has considered the use of mesh or tulle.

Tulle used in this study is widely used to make artificial beards, moustaches, and eyebrows. The finished products are then used in theaters and operas together with prosthetic adhesives. Tulle that was developed for these purposes is not affected by solvents, works seamlessly with prosthetic adhesives, and most importantly exhibits sufficient resistance to tearing and rupture. Against this backdrop of favorable and relevant benefits, the stage was set for this study to tap on these benefits by incorporating tulle into a maxillofacial prosthetic material. Moreover, it was previously described in a clinical report that a maxillofacial prosthesis made from a tulle-reinforced silicone elastomer material exhibited increased resistance against tearing and rupture at the edges without any esthetic deformation[22]. In view of this reported application, there was a further need to support the report with laboratory investigations.

A very commonly used maxillofacial prosthetic material, A-2186, was selected for this study because of its high tear strength alongside other good physical properties. Tulle was embedded in the silicone material and acted as a framework within the silicone matrix, thereby rendering the elastomer with significantly improved mechanical properties.

Tear resistance and tensile strength values of the study group were found to be significantly higher than the control group. These results concluded that tulle can be used to improve the mechanical properties of silicone elastomer. On the other hand, a lower value for elongation at break was observed in this study. This should not pose any serious problem because clinically, the elongation value obtained from the study group with tulle-incorporated elastomer was accepted as satisfactory for the use of maxillofacial prostheses.

From prosthesis longevity viewpoint, tear resistance is an important mechanical property. This is especially because the margins are particularly susceptible to degradation due to the poor tear resistance of silicone elastomer. In the present study, it was shown that the inherently strong mechanical properties of tulle imparted the needed strength to the structure of the silicone material. Therefore, in light of the significantly increased tear resistance of tulle-incorporated silicone elastomer, it can be accepted as a choice alternative to reduce the tearing of delicate edges of maxillofacial prostheses.

CONCLUSION

Within the limitations of this study, it was concluded that the use of tulle for the reinforcement of maxillofacial silicone elastomer provided the latter with improved mechanical properties, especially in terms of tear resistance. Nonetheless, these results should be further supported with more clinical studies.

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