ORIGINAL PAPER

EFFECTIVENESS OF ADDING BASALT FIBERS IN FLEXURAL STRENGTH OF DENTURE BASE ACRYLIC RESIN

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ABSTRACT

Introduction: Fracture of denture made of poly(methyl methacrylate) (PMMA) is considered a common clinical problem. Thus, several materials were used for improving the mechanical properties of PMMA. To the best of our knowledge, there is no information about the effect of adding basalt fibers in improving the mechanical properties of PMMA.

Objectives: This study evaluated the flexural strength of heat-polymerized acrylic resin denture reinforced with untreated chopped basalt fibers, chopped basalt fibers treated with monomer, silane, or phosphoric acid.

Material and methods: Sample size was equally divided into five groups: (1) Group C (PMMA un-reinforced with basalt fibers); (2) Group UBF (PMMA reinforced with untreated basalt fibers); (3) Group MBF (PMMA reinforced with basalt fibers treated with monomer); (4) Group SBF (PMMA reinforced with basalt fibers treated with silane); and (5) Group PhABF (PMMA reinforced with basalt fibers treated by phosphoric acid 35%). A 3-point bending test was carried out with a universal testing machine. Data were analyzed using one-way ANOVA test.

Results: Flexural strength of MBF and SBF groups was higher than C group, with a significant difference. However, the flexural strength of MBF was higher than UBF, SBF, and PhABF, with a significant difference. SBF group was significantly different from PhABF group.

Conclusions: PMMA reinforcement with basalt fibers treated with monomer improved the flexural properties.

Key words: dental materials, removable prosthodontics, acrylic resin, basalt fibers, mechanical properties, poly(methyl methacrylate) (PMMA).

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INTRODUCTION

Poly(methyl methacrylate) (PMMA) is the most frequently used material for fabricating removable dentures because of its' low cost, bio-compatibility, stability in the oral cavity, and acceptable aesthetics [1], despite its' low fracture resistance [2]. The fracture of dentures made of PMMA, which occurs in or outside the mouth, is still considered a frequent clinical problem that affects prosthodontic treatment [3]. To overcome the low fracture resistance of PMMA, several methods have been used, such as adding metal wires, plates or stainless-steel mesh, and organic or inorganic fibers (glass fibers, aramid fibers, carbon fibers, nylon, or ultra-high-modulus polyethylene fibers) [4]. Although the insertion of metal wires and plate improved the mechanical properties and thermal conductivity of PMMA, the esthetic appearance were poor [5]. Several studies reported that adding carbon and aramid fibers to PMMA make its' polishing difficult and may cause an esthetic problem [6]; however, polyethylene fibers increase the impact strength of PMMA and provide a good esthetic appear-

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ance, but the process of etching, preparing, and applying layers of woven fibers may be difficult and impractical [7]. Different types of glass fibers are commercially available, including E-glass, S-glass, R-glass, V-glass, and Cem-Fil. Among these, E-glass fibers are considered the best in improving the flexural strength, impact strength, toughness, and Vickers' hardness of acrylic resin flexural strength [8], whereas laboratory tests showed that PMMA dentures reinforced with glass fibers raised fatigue resistance up to 100 times in comparison with un-reinforced ones [2, 8]. Many factors affect the strength of fiber included, such as materials used, quantity, diameter, length, fiber form, location, orientation, adhesion of fibers to the matrix, and impregnation of fibers with polymer matrix [9].

Despite all the above-mentioned advantages of glass fibers, it was suggested that handling and achieving adequate impregnation of the fibers within the resin were difficult [10].

Nowadays, both industrial and academic world are focusing their research on the natural fibers that can be used as reinforcement, with the basalt ones as the most interesting due to their properties [11].

Basalt is a natural material that is found in volcanic rocks, with a melting temperature 1,500-1,700°C, and SiO_2 and Al_2O_3 are the main ingredients, according to chemical analyzing [12]. Basalt fiber was developed by the Moscow Research Institute of Glass and Plastic in 1953-1954, and its' first industrial production was completed in 1985 at Ukraine's fiber's laboratory [13].

Many advantages of basalt fibers make its' use increased rapidly in comparison with other fibers, such as good mechanical properties, high resistance to chemical attacks, low water absorption, good hardness, no risk to humans, high temperature resistance, high chemical stability, good resistance to alkaline and acids exposures, and thermal insulation [14].

The manufacturing process of basalt fibers is similar to that of glass fibers, but with less energy consumed and no additives, which make it inexpensive [12, 15].

OBJECTIVES

The purpose of this study was to compare the flexural strength between un-reinforced heat-polymerized denture-base acrylic resin and those reinforced with chopped basalt fibers. The null hypothesis was that incorporating chopped basalt fibers would not produce differences in the flexural strength of PMMA.

MATERIAL AND METHODS

Ethical approval for this study was obtained from ethical committee of the Damascus University (decision number 1754, obtained on May, 7th 2020). The sample size composed of thirty rectangular specimens (65 mm long, 10 mm wide, and 3mm thick), which were equally divided into five groups as follows:

1. Group C: conventional heat-processed acrylic resin (Vertex Regular®, Vertex-Dental B.V.; Zeist, The Netherlands) unreinforced with basalt fibers.
2. Group UBF: heat-processed acrylic resin reinforced with untreated basalt fibers (Technobasalt®; Kyiv, Ukraine).
3. Group MBF: heat-processed acrylic resin reinforced with basalt fibers treated with monomer (Vertex Regular, Vertex-Dental B.V.; Zeist, The Netherlands).
4. Group SBF: heat-processed acrylic resin reinforced with basalt fibers treated with silane solution (Ultradent Products; USA).
5. Group PhABF: heat-processed acrylic resin reinforced with basalt fibers treated with 35% phosphoric acid (Ultra-Etch, Ultradent, South Jordan, USA).

PREPARATION OF SPECIMENS

A pressure molding technique was applied to prepare all specimens according to the international standards of specimen manufacturing (ISO); thirty dental stone molds were prepared in dental flasks using wax patterns, manufactured by CAD/CAM technique with a specific dimension (65 × 10 × 3 mm) [16]. After the set of dental stone, the flask was placed into boiling water for 4-6 minutes to melt the wax, and then it was removed from water and exposed to water vapor to ensure there were no any residual wax or trace of impurities [17]. Thirty rectangular (65 mm long, 10 mm wide, and 3 mm thick) specimens were equally divided into five groups based on reinforcement and fiber treating method, as mentioned above.

BASALT FIBERS PREPARATION

Basalt fibers were 16 ± 2 µm in diameter, and were cut to a length of 5 mm [18, 19]. The cutting fibers were cleaned in boiling water for 10 minutes and air-dried before use [20] (Figure 1).

TESTED GROUPS

(1) Group UBF: specimens were modified by adding untreated basalt fibers.
(2) Group MBF: specimens were reinforced with monomer-treated basalt fibers. The basalt fibers were soaked in monomer (methyl methacrylate) for 10 minutes, and then were removed, and excess liquid was allowed to evaporate [21].
(3) Group SBF: specimens were modified by adding silanized basalt fibers. The cleaned fibers were silanated by being dipped into a silane solution for 5 min, and air-dried for 40 minutes [22].

FIGURE 1. Basalt fibers

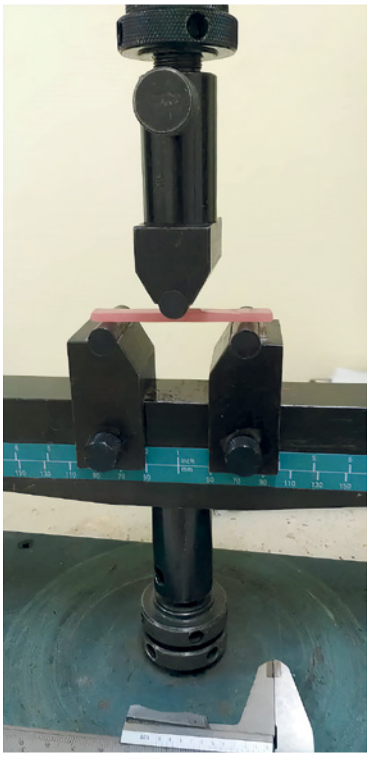

FIGURE 2. Universal testing machine

(4) Group PhABF: specimens were reinforced with basalt fibers, which were immersed in 35% phosphoric acid for 5 minutes, and then were cleaned and air-dried [23].

After monomer, silane, or phosphoric acid treatment of basalt fibers, the resin and fibers (2% by weight) were mixed thoroughly [17].

For control group, heat-polymerized acrylic resin was mixed according to the manufacturer's instruction, when the mixture reached a dough consistency, it was packed in the mold, tight closure was performed, and the final closure was at 24.13 N/mm^2 and kept for 30 min [24].

The acrylic resin was polymerized in water with long polymerization cycle; polymerizing unit (Hanau Engineering Company; Buffalo, NY, U.S.A.) was calibrated to increase the temperature to 74˚C after 1 hour, and then kept at 74ºC for 8 hours [25]. After polymerizing, cooling was done in water bath at room temperature, and deflasking was carefully completed.

Specimens were then evaluated under a stereoscopic microscope (Meiji; Japan) at 3.5x magnification to ensure the absence of voids or gross irregularities. Specimens were then finished with 400 and 600 grit sandpaper. Dimensions of all specimens were checked by digital caliper, which can detect any small changes, even 0.01 mm in size.

For the remaining experimental groups, specimens were processed the same way as control group; however, the difference was incorporating basalt fibers, which were transferred to the acrylic polymer by a tweezer before mixing with monomer.

All specimens were stored in distilled water for 7 days to remove the remaining unreacted monomer [25]. Then, all specimens were labeled before testing.

A 3-point bending test was carried out with a universal testing machine (DY-34, Adamel Lhomargy; France) at a crosshead speed of 2 mm/ min (Figure 2). A load was applied by a centrally located rod until fracture occurred. Ultimate transverse strength (TS) was calculated from the equation shown below[26]:

$$TS = 3 \times Fl/2 \times bh^2,$$

where F is the applied load, l is the span length (50.0 mm), b is the width of the specimen, and h is the thickness of the specimen.

STATISTICAL ANALYSIS

Normality of data was verified using Kolmogorov-Smirnov analysis, and the results revealed a normal distribution, therefore one-way analysis of variance (ANOVA) test was applied to determine any statistically significant differences between the experimental groups.

In this study, the level of significance (p-value) was set at 0.05, and all statistical analysis, including descriptive analysis, were performed using SPSS (version 23).

RESULTS

The mean results of flexural strength are shown in Table 1. The highest mean difference of flexural strength was in the MBF group (84.37 Mpa), followed by the SBF (75.8 Mpa), UPF (70.63 Mpa), and PHABF groups (69.47 Mpa), and the controlled group recorded the lowest mean number (65.5 Mpa).

One-way ANOVA test showed a statistically significant difference between the tested groups ($p < 0.05$), so the null hypothesis was rejected. The results showed that flexural strength values of the C group were lower than the MBF and SBF groups, with a significant difference, and the values of the MBF group was higher than in the UBF, SBF, and PhABF groups, with a significant difference (Table 2).

The values of the SBF group were higher than the PhABF group, with a significant difference (Table 2).

DISCUSSION

PMMA has become the most commonly used material to fabricate complete dentures and removable partial dentures due to its' low cost, bio-compatibility, ease of processing, stability in the oral cavity, and acceptable aesthetics [27]. However, it is not considered an ideal material because of its' inferior physical and mechanical properties [3]. It may get fractured intra-orally because of masticatory forces, while extra-orally high-impact forces could occur if the prosthesis dropped and subsequently, the denture may be fractured [3].

Denture base acrylic resins are accountable for different forces. Masticatory forces lead to fracture of a denture base, which is a flexural fatigue failure, while extra-orally impact forces can occur if the prosthesis is fallen and subsequently, the denture base can fracture [2].

Within the past few years, the studies have conducted that adding fillers or fibers to PMMA was a suitable solution to improve the physical and mechanical properties [15, 28].

This study revealed the effect of basalt fiber reinforcement and preparing basalt fiber methods on the flexural properties of PMMA resin. The results showed that the flexural strength of the UBF group was not significantly different from the control group ($p > 0.05$). Therefore, no benefit was observed in improving flexural strength by adding basalt fibers. However, the study demonstrated that the MBF group's specimens, which were reinforced by monomer-treated basalt fibers recorded the highest flexural strength. Impregnating the reinforcements allows the formation of a graded interface between the two different materials (basalt fibers and PMMA), and it may increase the flexural strength of a polymer fiber composite. Previous reports suggested that the increased flexural strength may depend on how effectively the fibers can be impregnated with acrylic resin [29, 30]. Therefore, the increased amount of MMA liquid could have an induced degradation effect on heat-polymerized denture base acrylic resin that may improve the incorporating process of basalt fibers. Integrating silanized basalt fibers improved the flexural strength of denture base acrylic resin, and it may be resulted from chemical attaching effect of silane. Flexural strength of the SBF group was less than that of the MBF group. This can be attributed to the tendency of silane-treated basalt fibers to clump together, accounting for the weakened samples. The results of this study revealed that flexural strength of PhABF specimens was low. Basalt fibers surface was modified by 35%, phosphoric acid, but the modification did not contribute to improvement of incorporating fibers into acrylic resin bulk. Weak attaching points may be the initiation as well as propagation of a crack.

TABLE 1. Mean values of flexural strength of the tested groups

Groups	Mean values of flexural strength (MPa)
C	65.50
UBF	70.63
MBF	84.37
SBF	75.80
PhABF	69.47

TABLE 2. One-way ANOVA test for flexural strength values to determine pair-wise comparisons between the groups

Comparison	Difference of mean	Standard error	*p*-value
C/UBF	–3.46667	1.65893	0.295
C/MBF	–16.57667	1.65893	0.000
C/SBF	6.23333	1.65893	0.024
C/PhABF	0.10000	1.65893	1.000
UBF/MBF	–13.11000	1.65893	0.000
UBF/SBF	–2.76667	1.65893	0.492
UBF/PhABF	3.56667	1.65893	0.272
MBF/SBF	10.34333	1.65893	0.001
MBF/PhABF	16.67667	1.65893	0.000
SBF/PhABF	6.33333	1.65893	0.022

Finally, adding monomer-treated basalt fibers to PMMA was less expensive in comparison with adding glass fibers. On the other hand, glass fiber provides better aesthetic qualities than basalt fibers. Therefore, it is preferable to use basalt fibers in hidden parts of the dentures and in cases, in which aesthetic needs are not important.

LIMITATION OF THE STUDY

Although we concluded that adding basalt fibers treated with monomer improve the flexural strength of PMMA, we cannot recommend using this technique in clinical practice without achieving additional in-vitro and clinical studies with a larger sample size, to evaluate the hardness, surface alteration, deflection, discoloration, and aesthetic acceptance. The above-mentioned outcomes are very important to be considerate before adopting this technique.

CONCLUSIONS

Within the limitation of this study, the following conclusions are drawn. Reinforcement of the denture acrylic resin with monomer treated basalt fibers increased the flexural strength of the PMMA fiber composite. Reinforcement of the denture acrylic resin with silanized basalt fibers increased the flexural strength of the PMMA fiber composite. Flexural strength of the SBF group specimens was less than that of the MBF group.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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