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Flexural Properties of a Denture Acrylic Resin Reinforced with Basalt Fibers

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Introduction

Polymethylmethacrylate (PMMA) is the most widely used material for fabricating removable partial or complete dentures; however, it has a relatively low fracture resistance [1,2]. To overcome the low fracture resistance of PMMA, several ways are used for reinforcement. The conventional method involves the use of metal wires, plates or stainless steel mesh as strengtheners of denture base polymers [3,4]. PMMA resins with either organic or inorganic fibers have been tested as suitable materials for prosthodontics [4-9]. Fibers used in polymer-fiber composites include glass fibers [5], sapphire whiskers [10], aramid fibers [11,12], carbon fibers [13], Nylon [14], or ultra-high-modulus polyethylene fibers [8]. The inclusion of metal wires and plate reinforcements enhances the strength of PMMA [15], and decreases the likelihood of denture fractures caused by strong biting or impact forces [4]. It also improves its thermal conductivity [15], but leads to poor esthetics for complete dentures [16]. It has been reported that carbon and aramid fibers strengthen PMMA; but they are generally difficult to polish, and may cause an esthetic problem [6,7,11,13,17]. Some investigators have found that the flexural properties of polyethylene fiber-reinforced denture base polymer showed significant increase [18]; whereas, others have found that inclusion of polyethylene fibers did not improve mechanical properties of PMMA resin [8]. Polyethylene fibers provide good esthetic qualities for dental applications; but the process of etching, preparing, and positioning layers of woven fibers may be difficult for the dental office [16,17]. Different types of glass fibers are produced commercially; these include E-glass, S-glass, R-glass, V-glass, and Cemfil [19]. Of these, E-glass fiber is claimed to be superior in flexural strength [5,20,21]. Dynamic in vitro tests showed that glass fiber reinforcement increased fatigue resistance of dental appliance up to 100 times compared with fatigue resistance of an unreinforced restoration [22]. By contrast, Tacir et al. [16] concluded that strengthening with glass fibers decreased the flexural strength of the acrylic resin polymers. Glass fibers, like polyethylene fibers, exhibit good esthetic properties [12,17,21-23].

Silanated glass fibers may be the fibers of choice for reinforcing denture base polymers because of their well-documented improvement in fracture resistance and good esthetic quality [21-23]. However, the manufacturing process of glass fibers requires considerable energy consumed and needs additives, which makes it expensive. Thus, it may be necessary to look for an alternative cheaper than glass fibers and enhances the flexural properties of PMMA resin.

Nowadays, both industrial and academic world are centering their attention toward the development of composites reinforced with natural fibers. In particular, among the natural fibers that can be used as reinforcement, the basalt ones represent the more interesting for their properties. Basalt is a natural material that is found in volcanic rocks originated from frozen lava, with a melting temperature comprised between 1500° and 1700°C [24,25]. Chemical analyzing of basalt revealed that SiO_2 is the main constituent and Al_2O_3 is the second one [25].

Basalt fiber was developed by Moscow Research Institute of Glass and Plastic in 1953-1954. It is a high-tech fiber invented by the former Soviet Union after 30 years of research and development, and its first industrial production furnace was completed in 1985 at Ukraine fiber laboratory [26]. This kind of fibers has comparable or better resistance than glass fibers [27], poses no risk to human beings [28], has high chemical stability, and good resistance to alkaline and acids exposure [29]. The manufacturing process of basalt fibers is similar to that of glass fiber, but with less energy consumed and no additives, which makes it inexpensive in comparison with glass fibers [30]. Due to its good properties, basalt fiber has gained increasing attention as a reinforcing material especially compared to traditional glass fibers [27,30].

The purpose of this study was to determine flexural properties of unreinforced heat-polymerized denture base acrylic resin and those reinforced with chopped basalt fibers. The study also aimed to compare the effect of incorporating monomer, silane, or phosphoric acid-treated basalt fibers on flexural properties of Polymer fiber composite. The null hypothesis was that incorporating chopped basalt fibers would not produce differences in the flexural properties of PMMA; and there would not be significant differences in the effect of the three tested methods of basalt fibers treatment on flexural properties of Polymer fiber composite.

Material and Methods

A compression molding technique was applied to preparing all specimens. Thirty dental stone molds were prepared in dental flasks using wax patterns of specific dimensions. Wax (Huge Cad Cam Wax, Pearson Lab) discs 98 mm were used to manufacture wax patterns measuring (65 x 10 x 3 mm) by CAD/CAM technology (DWX-51D 5-Axis Dental Milling Machine) [31]. Each wax pattern was invested in dental stone type III (Durguix, Hard natural stone, Protechno, Gerona, Spain). After the final set of the dental stone, the flask was placed in boiling water for 4 to 6 minutes to soften the wax and then it was removed from the water and opened. The residual wax was washed out with a stream of boiling water and the prepared molds were immersed in hot water to remove any trace of impurities and to facilitate the application of separating medium. The mold cavities obtained were used for the preparation of acrylic resin test specimens.

A power analysis (using G* Power Version 3.1.5) was undertaken to determine the required sample size. Thirty rectangular (65mm long,

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10mm wide and 3mm thick) specimens were equally divided into five groups based on reinforcement and fiber treating method. The control group (Group C) consisted of conventional heat-polymerized acrylic resin (Vertex Regular, Vertex dental, Zeist, The Netherland) specimens which were unreinforced with fibers. The remaining four experimental groups were made with the same conventional heat-polymerized acrylic resin, and the same resin reinforced with basalt fibers (Technobasalt, Kyiv, Ukraine) (Figure 1). The basalt fibers were 16 ± 2 μm in diameter and were cut with scissors to the lengths of 5mm [16]. The cut fibers were cleaned in boiling water for 10 minutes and air-dried before use.

Group UBF specimens were modified by incorporating an additional fiber reinforcement of untreated basalt fibers.

Group MBF specimens were reinforced with monomer treated basalt fibers. The basalt fibers were soaked in monomer (metyl methacrylate) (Vertex Regular, Vertex dental, Zeist, The Netherland) for 10 minutes to allow for better bonding with the acrylic resin [16,32]; after the fibers were removed from the monomer, excess liquid was allowed to dry.

Group SBF specimens of the same dimensions as above were modified by incorporating silanized basalt fibers. The cleaned fibers were silanated by being dipped into a silane solution (Ultradent Products. USA) for 5 min, and air dried for 40 minutes [8].

Group PhABF specimens were reinforced with basalt fibers which were treated by phosphoric acid 35% (Ultra-Etch, Ultradent, South Jordan, USA) for 5 minutes, and then they were cleaned and air-dried.

After monomer, silane, or phosphoric acid treatment of basalt fibers, the resin and fibers (2% by weight) [12,20] were mixed thoroughly to disperse the fibers.

For control group, the heat-polymerized acrylic resin was mixed according to manufacturer's instruction. When the mixture reached a dough consistency, it was packed in the mould and trial closure was performed [33]. The final closure was at 24.13 N/mm^2 and maintained for 30 min. The acrylic resin was polymerized in water with long polymerization cycle. The polymerizing unit (Hanau Engineering Company, Buffalo, N.Y., U.S.A.) was controlled to raise the temperature to 74˚C at 1 hour, and then kept at 74˚C for 8 hours. After polymerizing and cooling inside the water bath to room temperature, deflasking was carefully completed. Specimens were evaluated to ensure absence of voids or gross irregularities with ×3.5 magnification. Specimens were then finished with 400 and 600-grit sandpaper. The dimensions of all specimens were checked by digital caliper, which can record changes as small as 0.01 mm.

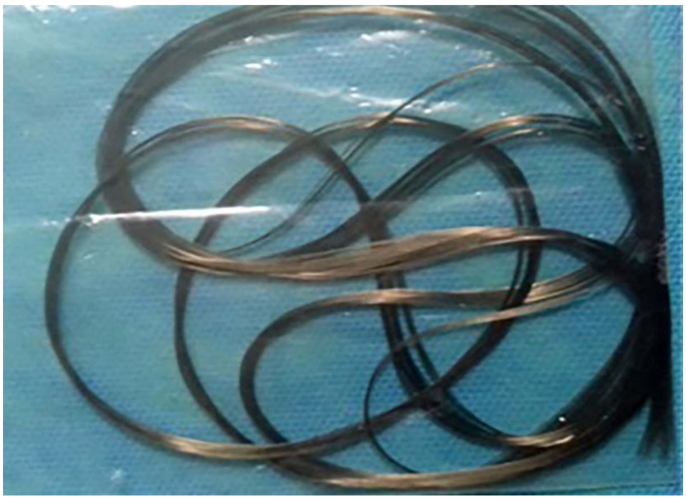

Figure 1: Basalt fibers (16 ± 2 μm in diameter).

For the remaining experimental groups, the specimens were polymerized and recovered in the same manner as the control group; however, the difference was incorporating basalt fibers to the acrylic polymer before mixing with monomer.

All specimens were stored in distilled water for 7 days, to remove the remaining unreacted monomer [34]. Specimens were labeled on each end before testing.

A 3-point bending test was carried out for the test specimens with a universal testing machine (DY-34 ADAMEL LHOMARGY, FRANCE) at a crosshead speed of 5 mm/min (Figure 2). A load was applied by a centrally located rod until fracture occurred. The ultimate transverse strength (TS) was calculated from the formula [35]:

$$TS = 3Fl / 2bh^2$$

Where F is the applied load (N) at the highest point of the load-deflection curve, l is the span length (50.0 mm), b is the width of the test specimen (3 mm), and h is the thickness of the test specimen.

Statistical analysis of the results was carried out with a one-way analysis of variance (ANOVA) and Tukey's multiple comparisons post hoc analysis for test groups, with a significance level of .05.

Results

The mean mechanical test result of each group is shown in (Table 1). The flexural strength of control group (unreinforced with basalt

Figure 2: A 3-point bending test by the universal testing machine (DY-34 ADAMEL LHOMARGY).

Table 1: The mean mechanical test results and standard deviations of test groups.

Group	N	Treatment	Flexural strength values (MPa)
C	6	Unreinforced with fibers	67.13 (1.60)
UBF	6	Untreated basalt fibers	70.60 (2.1)
MBF	6	Monomer treated basalt fibers	83.71 (2.19)
SBF	6	Silanized basalt fibers	73.37 (2.1)
PhABF	6	Basalt fibers treated by phosphoric acid	67.03 (2.11)
Standard deviations are given in brackets			

Table 2: Multiple comparison of all: study for flexural strength (Tukey HSD) groups.

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
C	UBF	-3.46667	1.65893	0.295	-8.9263	1.993
	MBF	-16.57667*	1.65893	0	-22.0363	-11.117
	SBF	-6.23333*	1.65893	0.024	-11.693	-0.7737
	PhABF	0.1	1.65893	1	-5.3597	5.5597
UBF	C	3.46667	1.65893	0.295	-1.993	8.9263
	MBF	-13.11000*	1.65893	0	-18.5697	-7.6503
	SBF	-2.76667	1.65893	0.492	-8.2263	2.693
	PhABF	3.56667	1.65893	0.272	-1.893	9.0263
MBF	C	16.57667*	1.65893	0	11.117	22.0363
	UBF	13.11000*	1.65893	0	7.6503	18.5697
	SBF	10.34333*	1.65893	0.001	4.8837	15.803
	PhABF	16.67667*	1.65893	0	11.217	22.1363
SBF	C	6.23333*	1.65893	0.024	0.7737	11.693
	UBF	2.76667	1.65893	0.492	-2.693	8.2263
	MBF	-10.34333*	1.65893	0.001	-15.803	-4.8837
	PhABF	6.33333*	1.65893	0.022	0.8737	11.793
PhABF	C	-0.1	1.65893	1	-5.5597	5.3597
	UBF	-3.56667	1.65893	0.272	-9.0263	1.893
	MBF	-16.67667*	1.65893	0	-22.1363	-11.217
	SBF	-6.33333*	1.65893	0.022	-11.793	-0.8737
*The mean difference is significant at the 0.05 level						

fibers) ranged from 63.40 to 67.60 MPa, with a mean of 65.5 MPa. In group UBF (reinforced with untreated basalt fibers), the flexural strength ranged from 69.20 to 72.70 MPa, with a mean of 70.63 MPa. The MBF group (reinforced with monomer treated basalt fibers) recorded the highest flexural strength; it ranged from 81.20 to 87.30 MPa, with a mean of 84.73 MPa. Incorporating silanized basalt fibers (SBF) increased the flexural strength; it ranged from 73.80 to 77.20 MPa, with a mean of 75.8 MPa. In PhABF group (reinforced with basalt fibers treated by phosphoric acid 35%) the flexural strength ranged from 69 to 70.20 MPa, with a mean of 69.47 MPa. One-way ANOVA test showed a statistically significant difference between the test groups ($P < 0.05$). Group C was significantly different from Group MBF and SBF. Group MBF was significantly different from Groups UBF, SBF and PhABF. Group SBF was significantly different from PhABF (Table 2).

Discussion

Denture base acrylic resins are subjected to many different stresses. Intra-orally, repeated masticatory forces lead to fracture of a denture base which is a flexural fatigue failure; while extra-orally, high-impact forces can occur if the prosthesis is dropped and subsequently the denture base can fracture [16].

With the increasing interest in finding out suitable solutions in material design to avoid fracture of the denture base, research on natural materials such as basalt has increased at a rapid rate [30]. This study revealed the effect of basalt fiber reinforcement and preparing basalt fiber methods on the flexural properties of PMMA resin.

Results showed that the flexural strength of UBF group was not significantly differed from control group ($p>0.05$). Thus, there were not any benefits by incorporating basalt fibers in improving flexural strength. However, the study demonstrated that group MBF specimens who 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 the polymer fiber composite. A previous report [36] suggested that increased flexural strength may be related to how effectively the fibers can be impregnated with the acrylic resin. So that, increased amount of MMA liquid could have induced a degradation effect on the heat-polymerized denture base acrylic resin that may improve the incorporating process of basalt fibers. Incorporating salinized 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 Group SBF specimens were less than of MBF. 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 phosphoric acid 35%, but the modification did not contribute to improve the incorporating of fibers into acrylic resin bulk. Weak attaching points may be the initiation and propagation of a crack.

Adding monomer treated basalt fibers is less cost 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 the hidden parts of the dentures.

Three-point flexural test, accepted by international standards for polymer materials, including ISO/DIS 1567:1999 Denture base polymers, is the most common technique of measuring flexural properties of denture bases [37]. According to ISO/DIS 1567:1999 flexural strength of heat-polymerized acrylic resin should be no less than 65 MPa [35]. The results of this study demonstrated that the mean flexural strength of all test groups was higher than that the required by ISO/DIS 1567:1999. Thus, all addition methods are suitable for clinical use. However, the flexural strength in Group MBF was significantly higher than that of other groups.

This study involved a limited analysis of a mechanical property for only one heat-polymerized denture base resin. Further research should be conducted to study other denture base resins, and how they could affect other physical and mechanical properties of these materials. The clinical implication of this study is that adding basalt fibers may have a positive effect on the strength of complete dentures. Also, using basalt fibers may save money, because they need less energy consumed and no additives, which makes it economical.

Conclusions

Within the limits of this study, flexural strength of PMMA specimens was positively influenced by adding basalt fibers. Also, preparing method of these fibers may have an effect on the flexural strength. According to the results of this study reinforcement the PMMA with monomer treated basalt fibers can be recommended.

Conflict of Interest

The current research is free of conflict of interest.

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