Comparative Study of the Mechanical Properties of Fiber-Reinforced Denture Base Resin

Ayşegül Köroğlu,[1] Tonguç Özdemir,[2] Ali Usanmaz[2]

[1]*Faculty of Dentistry, Ankara University, Ankara, Turkey*
[2]*Departments of Chemistry and Polymer Science and Technology, Middle East Technical University, Ankara, Turkey*

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ABSTRACT: Poly(methyl methacrylate) (PMMA) is used for removable prostheses. However, PMMA denture base resin does not meet all the mechanical requirements of prostheses. The aim of this *in vitro* study was to compare the transverse strength, modulus of elasticity, and impact strength values of nonreinforced heat-polymerized and microwave-polymerized denture base resin with those of denture base resin reinforced with continuous unidirectional E-glass, woven E-glass, and ultrahigh-molecular-weight polyethylene fibers. The mechanical properties of polymer reinforced with polyethylene fibers showed no significant increase in flexural properties. However, reinforcement with Stick fiber improved the mechanical properties. The test specimens that expressed low fracture strength values showed void spaces inside the test specimens. © 2009 Wiley Periodicals, Inc. J Appl Polym Sci 113: 716–720, 2009

Key words: dental polymers; fibers; mechanical properties

INTRODUCTION

Acrylic resins have many advantages, such as favorable working characteristics, ease of manipulation, accurate fit and polishability, use with inexpensive equipment, stability in the oral environment, and aesthetic appearance for extensive use as a denture base resin.[1,2] However, poly(methyl methacrylate)-based denture base resin is far from being a satisfactory denture material because it does not meet the mechanical requirements of prostheses.[3] The fracturing of acrylic resin dentures is an unresolved problem in prosthodontics.[4]

Fractures in dentures result from two different types of forces, namely, impact and flexure fatigue.[5] Most fractures of the complete denture occur inside the mouth during function, primarily because of resin fatigue. Outside the mouth, high-impact forces as a result of dropping the prostheses cause fractures.[1,6,7] The denture base resin is subjected to various stresses during function, including compressive, tensile, and shear stresses. Some of the factors responsible for denture base resin fracture include stress intensification, lack of balanced occlusion, increased ridge resorption that leads to an unsupported denture base, poor fit, deep incisal notching at the labial frena, sharp changes at the contours of the denture base, deep scratches, and induced processing stresses.[1,8]

To solve these problems and to improve the mechanical properties of dental polymers, many attempts have been made. One of the alternatives for solving the problem is to incorporate some type of reinforcement into the denture base resin.[9] Different fiber types, such as aramid, carbon/graphite, polyethylene, and glass fibers, have been added to denture base resins to improve their physical and mechanical properties. Fibers can be used in three forms, namely, continuous parallel, chopped, and woven.[10]

Several factors influence the mechanical properties of fiber-reinforced composites (FRCs). Adequate adhesion of the fibers to the polymer matrix is one of the most important factors for the strength of FRCs. Adhesion requires the proper impregnation of the fibers within the matrix. External forces are transferred from the continuous phase (resin) to the discontinuous phase; optimum adhesion is necessary for high performance in the composite.[11] Moreover, the inherent material properties of fibers and polymer matrices, fiber surface treatment (sizing), quantity of fibers, direction of fibers, position of fibers, and water sorption of FRC matrices affect the mechanical properties of FRCs.[12,13]

Although ultrahigh-molecular-weight polyethylene (UHMWPE) fibers have relatively good mechanical properties, criticism has been focused on findings that interfacial adhesion between polyethylene fibers and dental polymers is not adequate.[2,13] Dixon and Breeding,[14] Gutteridge,[15] and Williamson et al.[16] found that

Correspondence to: T. Özdemir, Turkish Atomic Energy Authority, 06530 Ankara, Turkey (tonguc.ozdemir@tr.net).

denture base resin reinforced with polyethylene fibers showed no significant increase in the flexural properties. Silanated glass fibers may be the fibers of choice for the reinforcement of denture base resin because of their well-documented improvement in the flexural properties and fatigue resistance and their good aesthetic qualities.[17] Glass fibers have been shown to improve the mechanical properties, especially fatigue resistance, impact strength, and flexural strength, of acrylic resin. This is because of the good adhesion of the glass fibers to the denture base resin and a low percentage of elongation at break of the glass fibers.[12]

The aim of this *in vitro* study was to compare the transverse strength, modulus of elasticity, and impact strength values of unreinforced heat-polymerized and microwave-polymerized denture base resin with those of denture base resin reinforced with continuous unidirectional E-glass, woven E-glass, and UHMWPE fibers.

EXPERIMENTAL

Two acrylic resins were used in the study: (1) conventional heat-polymerized resin (Meliodent, Bayer Dental, Newbury, Berkshire, United Kingdom) and (2) microwave-polymerized resin (Acron MC, GC Dental, Tokyo, Japan). The fiber reinforcing materials used are given in Table I.

Five specimens from each group were prepared for the mechanical tests. The transverse strength and impact strength were evaluated according to the ISO/DIS 1567 international standard.[18] Stainless steel molds with dimensions of $64 \times 10 \times 3.3$ mm^3 for flexural testing and $50 \times 6 \times 4$ mm^3 for impact testing were prepared to mold specimens from the resins.

The mixed powder-to-liquid ratio was 23.4 g : 10 mL for Meliodent resin and 100 g : 43 mL for the Acron MC microwave-polymerized resin. The corresponding doughing times were 6 and 15–20 min at 23 ± 2°C for each of these resins, respectively. Meliodent specimens were prepared in conventional metal denture flasks and cured in a thermostatically controlled dry heat oven for 1 h at 60°C and 2.5 h at 100°C. The specimens of Acron MC were prepared in fiber-reinforced plastic flasks (FRP Flask, GC Industrial Corp, Tokyo, Japan) and microwave irradiated according to the manufacturer's instructions for 3 min at 500 W. All specimen groups were bench-cooled before deflasking.[19]

Reinforced test specimens of Stick fibers and Stick Net fibers were cut to a length of 55 mm and a width of 6 mm. Ribbond fibers were cut to a length of 55 mm and a width of 4 mm for transverse strength tests. Tests specimens of Stick fibers and Stick Net fibers were cut to a length of 45 mm and a width of 4 mm, and Ribbond fibers were cut to a length of 45 mm and a width of 3 mm for impact tests.

The reinforcement content was calculated on weight percentage basis. For the transverse samples, the Stick fiber contents were 5.26–6.30%, the Stick Net contents were 0.74–0.82%, and the Ribbond contents were 0.93–1.02% for the Acron MC and Meliodent resins. For the impact test samples, the Stick fiber contents were 7.2–8.3%, the Stick Net contents were 0.61–0.75%, and the Ribbond contents were 0.9–1.09% for the Acron MC and Meliodent resins.

The fibers were wetted with a mixture of polymer powder and monomer. The Stick fibers were impregnated for 2 min, the Stick Net fibers were impregnated for 10 min, and the Ribbond fibers were impregnated for 5 min within a tin. Subsequently, the fibers were placed approximately in the middle of the acrylic resin doughs and compressed. The polymerization was carried out in the same way with unreinforced specimens.

All of the specimens were wet-ground with 200-, 400-, and 600-grit waterproof silicon carbide paper with an automatic polishing machine (Grin PO 2V grinder–polisher, Metkon A. Ş., Bursa, Turkey). Before testing, flexural test specimens were stored in a distilled water bath at 37°C for 50 ± 2 h, and impact test specimens were stored at 37°C for 2 weeks for full saturation.

A Lloyd universal testing machine (Lloyd Instruments, LRX, Fareham Hant, United Kingdom) with a crosshead speed of 5 mm/min was used for the three-point bending test. The specimens were placed on jigs that were 50 mm apart. This dimension represents the space between the maxillary molars in a complete denture. A load was applied to the center of the specimens until fracture occurred. The transverse strength (S) was calculated from the formula

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

where F is the maximum load applied (N), l is the distance between supports (span length = 50 mm),

TABLE I
Dental Fiber Systems Used in This Study

Group	Dental fiber system	Manufacturer	Physical structure	Chemical structure
1	Ribbond	Ribbond, Inc., Seattle, WA	Woven UHMWPE fiber	Polyethylene
2	Stick	StickTech, Ltd., Turku, Finland	Continuous unidirectional fiber	E-glass
3	Stick Net	StickTech, Ltd., Turku, Finland	Woven	E-glass

b is the width of the specimen (10 mm), and h is the thickness of the specimen (3.3 mm). The elastic modulus (E) was calculated from the formula

$$E = Fl^3/4bh^3d$$

where d is the deflection (mm). The impact test was carried out with a Charpy-type impact tester (Hounsfield Plastic Impact machine, Tensometer Ltd., Croydon, England), and the impact strength (I) was calculated from the following formula:

$$I = E/WT(\mathrm{J/m^2})$$

where E is the energy (which breaks the test specimen), W is the width of the specimen, and T is the thickness of the specimen. The mean values and the standard deviations of the transverse strength, elastic modulus, and impact strength for each group were calculated to compare the reinforced specimen groups with each other and with the specimens without fiber reinforcement. Mean values and standard deviations were calculated for all groups of specimens. Analysis of variance and Duncan tests were applied for the statistical studies. A Pro-Series high-performance charged coupling device camera (model 2252-1040/0000, San Diego, CA) was used to investigate the alignment of the fibers in the acrylic resin after the mechanical tests.

RESULTS AND DISCUSSION

The calculated mean values and standard deviations of the transverse strength, elastic modulus, and impact strength data are given in Figures 1–3, respectively. In general, the strength of fiber composite depended on the quantity of fibers,[20] orientation of fibers, and interfacial adhesion between the fiber and the polymer matrix.[21] The mechanical properties of the polymer reinforced with polyethylene fibers showed no significant increase in the flexural properties in both acrylic resins. This finding was parallel with those of previous studies by Dixon and Breeding,[14] Gutteridge,[15] and Williamson et al.[16] This may have been due to the inadequate interfacial adhesion between the acrylic resin and fiber with woven structure, which were not chemically compatible and also to the orientation of woven fiber chains with amorphous entangled chains of resin.

The mechanical properties of the Meliodent samples examined in this study were similar to the results obtained by Uzun et al.,[10] in which the samples were polymerized by a conventional water bath. The inclusion of Stick Net and Ribbond fibers decreased the mean transverse strength and flexural modulus of the reinforced denture base resins, which was attributed to the weak interfacial adhesion of the resins to the fibers and to the unsatisfactory mixing of the monomer and polymer. Generally, cut fibers have random orientations and give better improvement in some

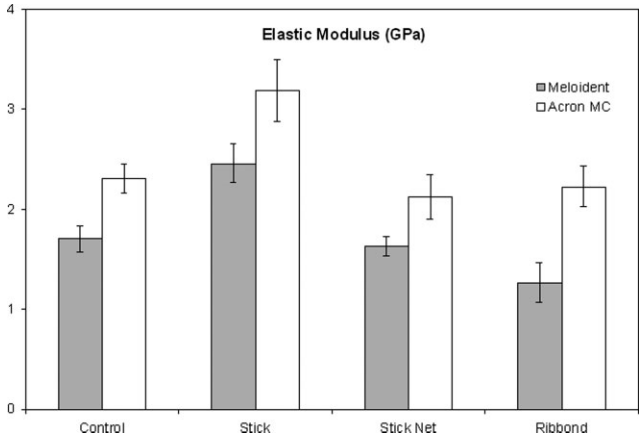

Figure 2 Change in the elastic modulus with the type of resin and fiber.

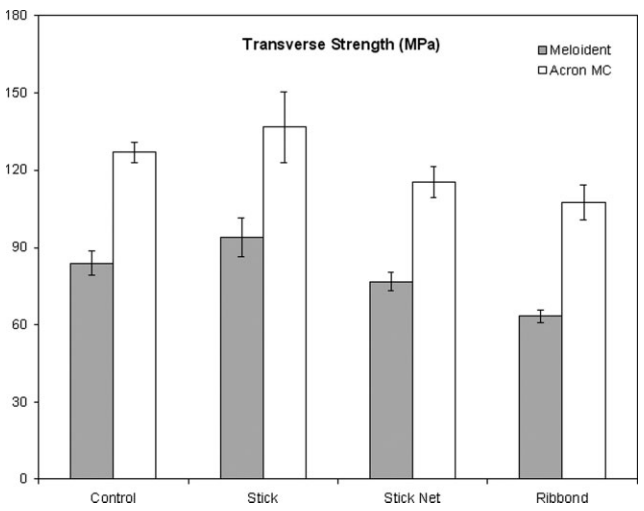

Figure 1 Change in the transverse strength with the type of resin and fiber.

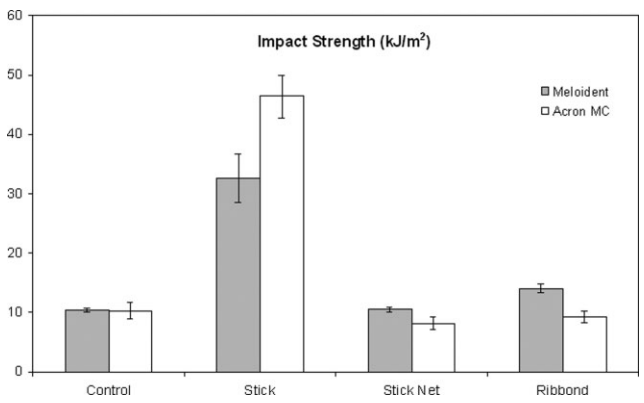

Figure 3 Change in the impact strength with the type of resin and fiber.

mechanical properties than long cut fibers. However, reinforcement with Stick fiber improved the mechanical properties. As shown in Figure 4, the Stick reinforcement properly aligned in the acrylic resin and gave a better interfacial adhesion compared with the Stick Net and Ribbond fibers. These were observed in an optical microscope investigation. However, the nature of adhesion will be investigated in detail in a future study.

The distribution of polyethylene fibers in a single direction was not possible because of the manual placement of fibers. This, as given in many textbooks, might be a reason for the decrease in mechanical properties. The test specimens that expressed low fracture strength values showed void spaces, which were observed under optical microscopy, inside the test specimens. These voids and nonadequate impregnation probably decreased the mechanical properties of the fiber composites (Fig. 5).

The mean of the all transverse strength test results for Acron MC was significantly different than that of the Meliodent resin ($p < 0.05$). The transverse strength results show that the fiber factor and acrylic resin interaction was not statistically significant. There was no statistical significance between the mean transverse strength of the Stick and control groups for both the Meliodent and Acron MC resin types, and these results were also valid for the Stick Net and control groups. The difference between the mean transverse strengths of the control group and Ribbond fiber group was statistically significant ($p < 0.05$). In another words, by 95% confidence, the transverse strength of the Ribbond fiber reinforced samples were different than that of the control group. Moreover, the Ribbond fibers had the lowest transverse strength values for both the Meliodent and Acron MC resins.

The mean of the all of the elastic modulus test results for Acron MC was significantly different than

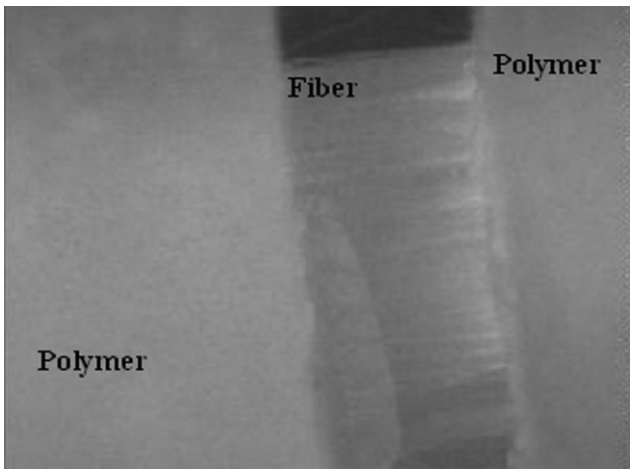

Figure 4 Microwave-polymerized denture base material with Stick fiber.

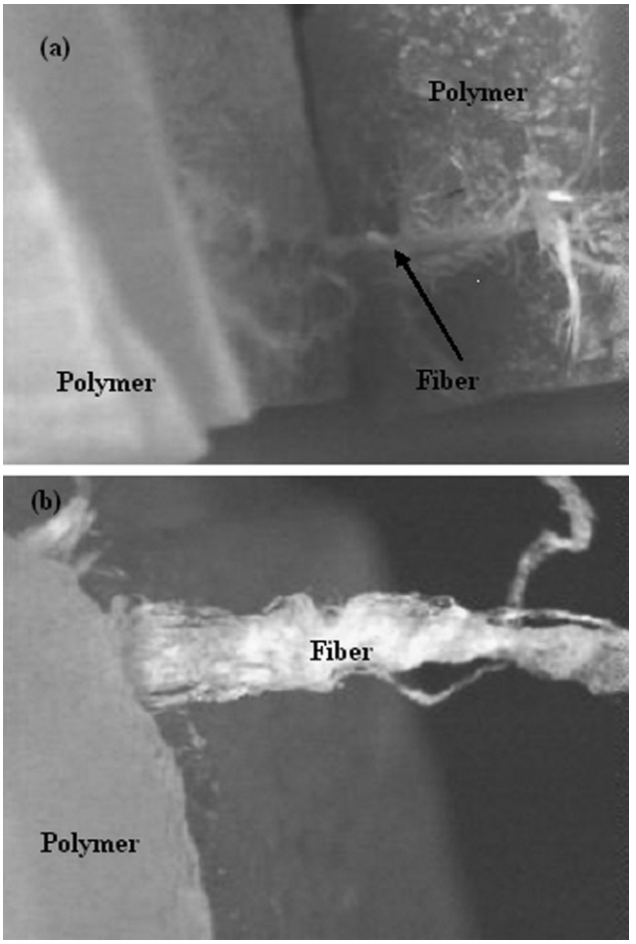

Figure 5 Polymerized denture base material with Ribbond fiber: (a) heat cured and (b) microwave polymerized.

that of the Meliodent resin ($p < 0.05$). Acron MC had a higher elastic modulus compared with Meliodent, regardless the type of fiber. The fiber factor and acrylic resin interaction was not statistically significant. The difference between the mean transverse strength of the control group and Stick Net and Ribbond groups was not statistically significant; however, the difference between the mean transverse strength of the control group and Stick group was statistically significant ($p < 0.05$) for both the Meliodent and Acron MC cases. The highest elastic modulus was obtained for Acron MC and Stick fiber.

The impact test results show that the Stick fiber group was significantly different from the other fiber groups for the both the Acron MC and Meliodent resins. The difference in the impact strength of the Acron MC and Meliodent resins with Stick fiber was statistically significant ($p < 0,05$). The highest impact strength was obtained for Acron MC and Stick fiber.

CONCLUSIONS

Microwave polymerization resulted in a higher transverse strength and flexural modulus compared

with heat polymerization in the denture base resin. Stick Net fibers decreased the mechanical properties compared with Stick fibers. Acron MC had a higher elastic modulus compared with Meliodent, regardless of the type of fiber. Stick fibers improved the mechanical properties. Moreover, Ribbond fibers had the lowest transverse strength values for both the Meliodent and Acron MC resins.

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