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**ORIGINAL ARTICLE**

# Reinforcing effect of glass-fiber-reinforced composite on flexural strength at the proportional limit of denture base resin

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**Abstract**

***Objective.*** To evaluate the reinforcing effect of fiber-reinforced composite (FRC) on flexural strengths at the proportional limit (FS-PL) of a denture base resin. ***Material and methods.*** Bar-shaped acrylic resin specimens and maxillary acrylic resin complete denture specimens were fabricated. The FS-PL of the reinforced bar-shaped specimens was tested. Novel FRC, FibreKor, Remanium, Palatal Bar Wire, and Clasp-Wire were used as reinforcing materials. Likewise, the compressive strength at the proportional limit (CS-PL) of the reinforced maxillary denture specimens was tested. ***Results.*** The FS-PL of the bar-shaped specimens reinforced with the FRCs was significantly higher than that of the unreinforced specimens. The FS-PL of the bar-shaped specimens reinforced with the 1.0-mm-thick FRC was similar to the FS-PL of specimens reinforced with Remanium or Palatal Bar Wire. The FS-PL of specimens reinforced with the 1.5-mm-thick FRC was significantly higher than with the metal-reinforcing materials. The reinforcing efficiency of the 1.0-mm-thick FRC was 1.78–1.79 and of the 1.5-mm-thick FRC 3.14–3.27. The reinforcing effect of the FRC on the CS-PL of the maxillary denture specimen was similar to the effect on the FS-PL of the bar-shaped specimens. The reinforcing efficiency was 1.40 for the 1.0-mm-thick FRC and 1.67 for the 1.5-mm-thick FRC. ***Conclusion.*** The unidirectional glass-fiber-reinforced composite had a reinforcing effect on the flexural strength at the proportional limit of the denture base resin.

**Key Words:** *Denture base resin, fiber-reinforced composites, flexural strengths at proportional limit, reinforcing effect, reinforcing efficiency*

## Introduction

Conventional heat-accelerated acrylic resins are still the predominant denture base materials being used by practitioners. They are typically low in strength, soft and fairly flexible, brittle on impact, and fairly resistant to fatigue failure [1]. Metal wire and braided wire plates have been investigated as reinforcements of acrylic resin dentures [2–7] and have been used clinically.

Recently, the frameworks of fixed partial dentures [8–14], implant-supported overdentures [15], and post materials [16,17] have been made from fiber-reinforced composite (FRC) materials consisting of glass fibers embedded in a methacrylate resin. Investigators have studied continuous glass fibers used to reinforce denture base resin when the fibers were incorporated within the acrylic resin directly [2], after dipping in MMA liquid [18–22], or after dipping in a PMMA-MMA mixture [5,19,23–26]. Clinical studies [27,28] have reported that denture bases can be reinforced with fibers in two ways: using total fiber reinforcement (TFR) with the fiber weave, or using partial fiber reinforcement (PFR) placed at the weak area of the denture with the continuous fiber. However, a longer follow-up period is necessary to show the clinical usefulness of E-glass PFRs. In recent studies investigating the static strength [26] and flexural fatigue [29] of denture base polymer reinforced mainly with FRC, it was revealed that placing the FRC reinforcements on the tensile side resulted in considerably higher flexural strength and flexural modulus values compared with placing the same quantity of FRC reinforcements on the compression side [26]. Fiber reinforcement placed on the tensile side reinforced the test specimens more effectively against repeated bending than did fiber reinforcements on the compression side [29]. Polymerized FRC material is considered to be as useful as metal for reinforcing denture base resin, but the reinforcing effect of

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FRCs on the flexural strength of denture base resins has not yet been investigated.

In many studies, the flexural strength of acrylic denture base resin has been evaluated at the fracture load or the highest load. Dental plastics, such as denture bases, typically exhibit considerable plastic deformation before failure. The plastic deformation of a material beyond its proportional limit permanently alters the dimensions of the material. Thus, plastic deformation is unacceptable for dental materials, such as denture base materials, that rely on dimensional stability as a prerequisite for their use [30]. A denture material should have a proportional limit sufficiently high that permanent deformation does not result from the stress applied during mastication [1]. Therefore, estimation of the proportional limit of a material using its resistance to plastic deformation is of significant clinical value. The resistance of denture polymers to plastic deformation under a flexural load has been evaluated in several studies [30–34], but little is known about the flexural strength at the proportional limit of acrylic resins reinforced with FRC.

It was hypothesized in this study that unidirectional glass-fiber-reinforced composite has a reinforcing effect on the flexural strength at the proportional limit of the denture base resin that is equal to the reinforcing effect of metal reinforcement. The purpose of this study was to investigate the reinforcing effect of fiber-reinforced composite on the flexural strength at the proportional limit of bar-shaped denture base resin specimens and on the compressive strength at the proportional limit of a maxillary acrylic resin complete denture.

## Material and methods

Silanized E-glass fibers (20 µm and 30 µm in diameter; Asahi Fiber Glass Co., Tokyo, Japan), dimethacrylate resin (UDMA-TEGDMA) and a denture base resin (Lucitone199, Lot no. (P):0301219, (L):0206073; DENTSPLY International Inc., York, Pa., USA) were selected for the study. UDMA (urethane dimethacrylate, Lot no. SH-500B; Negami Chemical Industrial Co. Ltd., Ishikawa, Japan) and TEGDMA (triethyleneglycol dimethacrylate, NK-Ester, Lot no. 0604R; Shin-Nakamura Chemical Co. Ltd., Wakayama, Japan) were mixed at a ratio of 1:1. As a light initiator (0.7 wt%), CQ (camphorquinone, Lot no. C0014; Tokyo Kasei Co. Ltd., Tokyo, Japan) and DEAM (2-dimethylaminoethyl methacrylate, Lot no. M0082; Tokyo Kasei Co. Ltd., Tokyo, Japan) were used at a ratio of 1:2.

The glass fibers were impregnated with the dimethacrylate resin liquid and then packed in a stainless steel mold (0.5 mm, 1.0 mm, or 1.5 mm thick, 5.0 mm wide and 65 mm long). The highly filled bar-shaped specimens containing each diameter of glass fibers were cured in the mold under a glass cover for 1 min with a light-curing unit (Visio Alfa; 3M ESPE, Seefeld, Germany), removed from the mold, and post-cured with a light-curing unit (UniXS II; Heraeus Kulzer, Wehrheim, Germany) for 3 min. The polymerized FRC material was sandwiched in the middle of the denture base resin in a doughy state and placed parallel to the long axis of the specimen. The resin was then heat-polymerized according to the manufacturer's instructions in a gypsum mold (2.5 × 10 × 65 mm).

A denture base material without reinforcement and denture base materials reinforced with a commercially available FRC and metal wire served as controls. The reinforcing material of a commercially available FRC (FibreKor, Lot No. 115908; Pentron Corp., Wallingford, Ct., USA) was formed into a rectangular specimen (1.0 mm thick × 5 mm wide × 65 mm long). The FibreKor was cured in the mold under a glass cover for 1 min with a light-curing unit (Alfa Light II N; Morita, Tokyo, Japan), removed from the mold, and post-cured with a light-curing unit (Alfa Light II N, Morita) for 15 min. Three kinds of metal wire were used to reinforce the specimens: 1) 1.0-mm-diameter × 65-mm-long round wire (Sun-Cobalt Clasp-Wire, Lot No. A640563; Dentsply-Sankin K.K., Tochigi, Japan), 2) 1.0-mm-thick × 2.0-mm-wide × 65-mm-long half-round hard wire (Remanium, Lot No. 51660; Dentaurum, Pforzheim, Germany), and 3) 1.0-mm-thick × 2.7-mm-wide × 65-mm-long half-round wire (Sun-Cobalt Palatal Bar Wire, Lot No. E630162; Dentsply-Sankin K.K., Tochigi, Japan). The surfaces of the metal reinforcements were sandblasted with 50 µm grain-sized alumina (Aluminous Powder WA 360; Pana Heraeus Dental Inc., Osaka, Japan) for 10 s at an emission pressure of 0.3 MPa using a grit blaster (Micro Blaster; Comco Inc., Burbank, Calif., USA). The nozzle was positioned at a right angle approximately 10 mm from the surface of the metal reinforcement. The sandblasted metal reinforcements were then cleaned in distilled water for 10 min in an ultrasonic cleaner (Bransonic 2510 J-MTH; Branson Ultrasonics Corp., Danbury, Ct., USA). Immediately after the cleaned metal reinforcements were dried, a metal conditioner (Alloy Primer, Lot: 00218A; Kuraray Medical Inc., Tokyo, Japan) was applied to the sandblasted surfaces with a sponge pellet. The specimens reinforced with these materials were fabricated in the same way as the specimens reinforced with the FRCs (Table I and Figure 1).

The accuracy of the dimensions was verified with a micrometer at three locations to within a 0.03 mm tolerance for the thickness and width. Ten specimens were fabricated for each group. The specimens were immersed in distilled water at 37°C for 50 h.

The flexural strength at the proportional limit (FS-PL) of the specimens was tested. Each specimen

Table I. Classification of the reinforcing materials of the bar-shaped specimens

| | Group | Reinforcing material | Size |
|---|---|---|---|
| A. | Bulk | None | |
| B. | 0.5 mm–20 μm | FRC | 0.5-mm thick, 5.0-mm wide, 65-mm long (E-glass fiber: 20-μm diameter) |
| C. | 0.5 mm–30 μm | FRC | 0.5-mm thick, 5.0-mm wide, 65-mm long (E-glass fiber: 30-μm diameter) |
| D. | 1.0 mm–20 μm | FRC | 1.0-mm thick, 5.0-mm wide, 65-mm long (E-glass fiber: 20-μm diameter) |
| E. | 1.0 mm–30 μm | FRC | 1.0-mm thick, 5.0-mm wide, 65-mm long (E-glass fiber: 30-μm diameter) |
| F. | 1.5 mm–20 μm | FRC | 1.5-mm thick, 5.0-mm wide, 65-mm long (E-glass fiber: 20-μm diameter) |
| G. | 1.5 mm–30 μm | FRC | 1.5-mm thick, 5.0-mm wide, 65-mm long (E-glass fiber: 30-μm diameter) |
| H. | FibreKor | FibreKor | 1.0-mm thick, 5.0-mm wide, 65-mm long |
| I. | Clasp-Wire | Sun-Cobalt Clasp-Wire | 1.0-mm-diameter round wire, 65-mm long |
| J. | Remanium | Remanium | 1.0-mm-thick half-round hard wire, 2.0-mm wide, 65-mm long |
| K. | Bar Wire | Sun-Cobalt Palatal Bar Wire | 1.0-mm-thick half-round wire, 2.7-mm-wide, 65-mm-long |

was placed on a 50-mm-long support for three-point flexural testing. A vertical load was applied at the mid-point of the specimen at a cross-head speed of 5 mm/min on a load testing machine (AGS-J; Shimadzu Co., Tokyo, Japan). The FS-PL (N) was determined from each load/deflection graph (Figure 2).

Representative specimens of the denture base material reinforced with the 20 and 30 μm FRCs and FibreKor were embedded in resin and prepared for scanning electron microscopy (SEM, JSM-6330F, JEOL, Tokyo, Japan). Micrographs of the cross sections of these specimens were taken at 40 × and 500 × to study the quality of the interface between the fibers and their matrix.

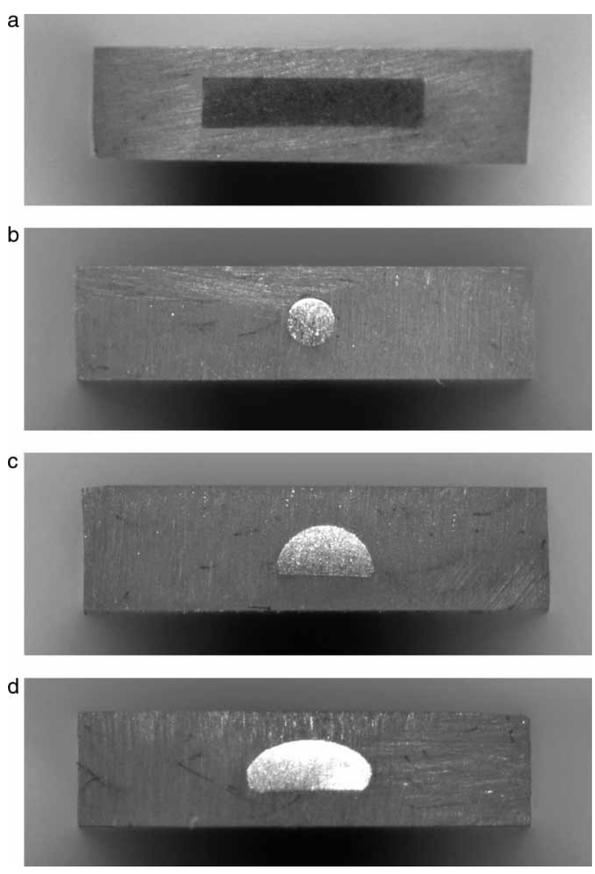


Figure 1. Representative cross sections of bar-shaped specimens reinforced with (a) FRC (1.0 mm–20 μm), (b) Clasp-Wire, (c) Remanium, and (d) Bar Wire.

A maxillary acrylic resin complete denture reinforced with the FRC was investigated. As controls, a resin denture without reinforcement and a resin denture reinforced with Remanium were tested. Combined precision impressions of the maxillary edentulous model (G1-402; Nissin Dental Products Inc., Kyoto, Japan) were made with elastomeric silicone material (Exafine injection/putty type; GC Corp., Tokyo, Japan), and a working cast was fabricated with high-strength plaster stone (Surstone; GC Corp., Tokyo, Japan). Thermoplastic sheets (Erkodur; Erkodent Erick Kopp GmbH, Pfalzgrafenweiler, Germany) were used to form thermoplastic denture bases on a working cast by vacuum forming (Erkopress 2002; Erkodent Erick Kopp GmbH). The thickness of the thermoplastic denture bases was adjusted to 2.5 mm by carefully trimming and adding wax when necessary; they were then measured with calipers to ensure uniformity.

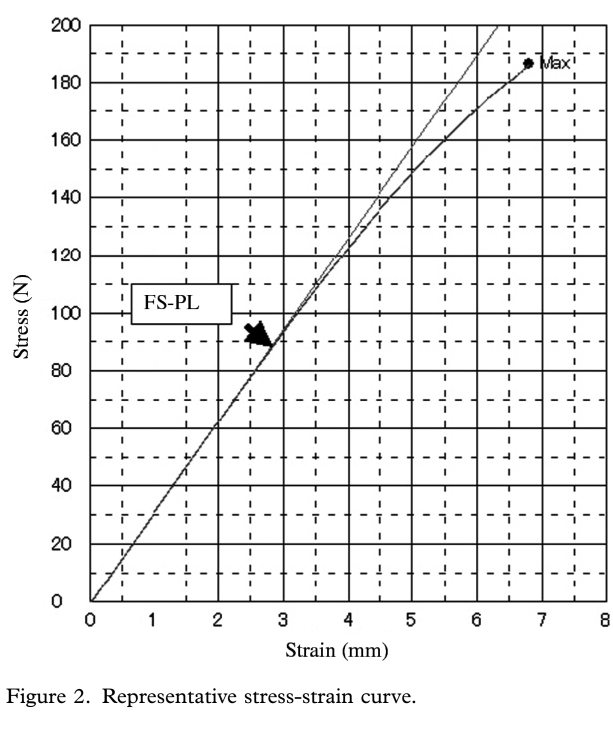


Figure 2. Representative stress-strain curve.

Table II. Classification of the reinforcing materials of the maxillary complete dentures

| | Group | Reinforcing material | Size |
|---|---|---|---|
| I. | Bulk | None | |
| II. | 1.0 mm–20 μm | FRC | 1.0-mm thick, 5.0-mm wide, 55-mm long (E-glass fiber: 20-μm diameter) |
| III. | 1.5 mm–20 μm | FRC | 1.5-mm thick, 5.0-mm wide, 55-mm long (E-glass fiber: 20-μm diameter) |
| IV. | Remanium | Remanium | 1.0-mm-thick half-round hard wire, 2.0-mm wide, 55-mm long |

After the artificial teeth (Real crown resin teeth anteriors, BioAce resin teeth posteriors; Shofu Inc., Kyoto, Japan) were arranged, the wax dentures were invested with dental stone in denture flasks. The wax was eliminated and the thermoplastic sheets removed. The 1.0–20 μm FRC, the 1.5–20 μm FRC, and the Remanium were used as reinforcing materials (Table II). The FRCs and Remanium were formed into a horseshoe shape on a working cast. The reinforcing material was embedded in the denture base resin in the doughy state and placed under the ridge lap surfaces of the teeth from the left 2nd premolar to the right 2nd premolar of the denture. The reinforcing material was conventionally packed and the resin was heat-polymerized in accordance with the manufacturer's instructions. Five specimens were fabricated for each group. All the dentures were stored in 37°C distilled water for 50 h before testing.

The compressive strength at the proportional limit (CS-PL) (N) was measured using a load testing machine at a cross-head speed of 5.0 mm/min. A compressive load was applied to each maxillary complete denture with a 25-mm-diameter ball attachment (Figure 3). Application of the downward load along the midline of the tissue surfaces of the denture was designed to be equivalent to the upward load on both sides, combined with unyielding support in the center of the plate [6,35,36].

The data were analyzed statistically using a one-way analysis of variance (ANOVA) (STATISTICA; StatSoft Inc., Tulsa, Okla., USA), and a Newman-Keuls post hoc comparison (STATISTICA; StatSoft Inc., Tulsa, Okla., USA) was applied when appropriate (95% confidence level). All tests were performed under uniform atmospheric conditions of $23.0 \pm 1$°C and $50 \pm 1$% relative humidity.

Figure 3. Fracture strength test using compression load assembly.

The fiber content (vol%) of the FRCs was determined using an ashing method [25,37,38]. A representative portion of each FRC was desiccated for 36 h at 37°C and weighed to an accuracy of 1 mg. The specimen was then ashed for 45 min at 700°C. Each specimen was weighed before and after ashing on an electronic scale (A 120 S; Sartorius GmbH, Goettingen, Germany). The fiber content was calculated according to the following formula:

$$V_g = W_g/\rho_g \div (W_g/\rho_g + W_r/\rho_r)$$

where $V_g$ = volume percentage (vol%) of fiber, $W_g$ = weight percentage of fiber, $\rho_g$ = density of the fiber (2.55 g/cm$^3$), $W_r$ = weight percentage of the matrix, and $\rho_r$ = density of the matrix (1.227 g/cm$^3$).

## Results

One-way ANOVA revealed significant differences ($p < 0.05$) in the flexural strength at the proportional limit (FS-PL) of the reinforced bar-shaped denture base resin, which was attributed to the various reinforcing materials (Table III). The FS-PL of the denture base resin reinforced with the FRC was significantly higher than that of the unreinforced denture base resin. There was no significant difference between the 20 μm FRC specimens and the 30 μm FRC specimens. Post-hoc analysis showed that the FS-PL increased with the increasing thickness of the reinforcing material fabricated with the FRC. With regard to the reinforcing materials that

Table III. Flexural strength at proportional limit (N) of bar-shaped specimens reinforced with several reinforcing materials and reinforcing efficiency (times) of the reinforcing material on the bulk material ($n = 10$)

| | Group | Mean (SD) | Reinforcing efficiency |
|---|---|---|---|
| A. | Bulk | 28.0 (0.8)$^{a*}$ | 1 |
| B. | 0.5 mm–20 μm | 37.7 (2.9)$^{b}$ | 1.35 |
| C. | 0.5 mm–30 μm | 44.1 (5.6)$^{b,c}$ | 1.57 |
| D. | 1.0 mm–20 μm | 50.1 (3.0)$^{c}$ | 1.79 |
| E. | 1.0 mm–30 μm | 49.9 (4.3)$^{c}$ | 1.78 |
| F. | 1.5 mm–20 μm | 87.8 (13.6)$^{d}$ | 3.14 |
| G. | 1.5 mm–30 μm | 91.6 (12.0)$^{d}$ | 3.27 |
| H. | FibreKor | 40.1 (4.4)$^{b}$ | 1.43 |
| I. | Clasp-Wire | 31.7 (6.2)$^{a}$ | 1.13 |
| J. | Remanium | 51.5 (1.1)$^{c}$ | 1.84 |
| K. | Bar Wire | 49.4 (2.1)$^{c}$ | 1.76 |

*a, b, c and d denote no significant differences ($p > 0.05$).

were 1.0 mm thick or 1.0 mm in diameter, the FS-PL of the denture base resin reinforced with the FRC was significantly higher than that of FibreKor and the Clasp Wire, and similar to the FS-PL of the Remanium and the Bar Wire. The FS-PL of the denture base resin reinforced with the 1.5-mm-thick FRC was the highest. The efficiency (times) of the reinforcing material on the bulk material was calculated (Table III). The reinforcing efficiency of the 1.0-mm-thick FRC was 1.78–1.79, while that of the 1.5-mm-thick FRC was 3.14–3.27.

SEM micrographs taken at 40 × and 500 × magnifications of representative specimens of the denture base material reinforced with the 20 and 30 μm FRCs showed close distribution of the glass fibers in the matrix. The glass fibers in the matrix of FibreKor were widely distributed. Impregnation of the glass fibers within the matrix was generally good (Figure 4).

One-way ANOVA revealed significant differences ($p < 0.05$) in compressive strength at the proportional limit (CS-PL) of the reinforced maxillary dentures, which were attributed to the various reinforcing materials (Table IV). The reinforced maxillary dentures had higher CS-PL than the dentures without reinforcement. The CS-PL values of the dentures reinforced with the 1.0-mm-thick FRC and the Remanium were not significantly different, and the CS-PL of the denture reinforced with the 1.5-mm-thick FRC was significantly higher. The reinforcing efficiency of the 1.0-mm-thick FRC was 1.40, while that of the 1.5-mm-thick FRC was 1.67 (Table IV).

The fiber contents of the 20 μm FRC, the 30 μm and FibreKor were 62.0 vol%, 63.4 vol%, and 44.4 vol%, respectively.

## Discussion

The present investigation introduced a clinically relevant means of studying the strength of denture bases reinforced with FRC using bar-shaped specimens and maxillary denture specimens. Evaluation of the proportional limit of the reinforced denture base was considered appropriate because stresses higher than the proportional limit typically initiate permanent plastic deformation and render the denture unusable. A standard textbook [1] indicates that the proportional limit of heat-polymerized denture base resin (26.2 MPa) is lower than its flexural strength (78 MPa). A denture material should have a proportional limit sufficiently high that permanent deformation does not result from the stress applied during mastication [1], which may cause loss of retention or loosening of the teeth in the denture base [1]. In this study, light-curing FRCs were used, which are applied not only for reinforcement during fabrication of a denture in the laboratory but also during chairside repair of dentures. The novel FRC was cured for 1 min with a light-curing unit (Visio Alfa; 3M ESPE) to correctly shape it and then post-cured for 3 min with a light-curing unit (UniXS II) to achieve mechanical strength.

The bar-shaped specimens were investigated first. The FS-PL of the unreinforced heat-polymerizing denture base resin (Lucitone 199) was 33.6 MPa

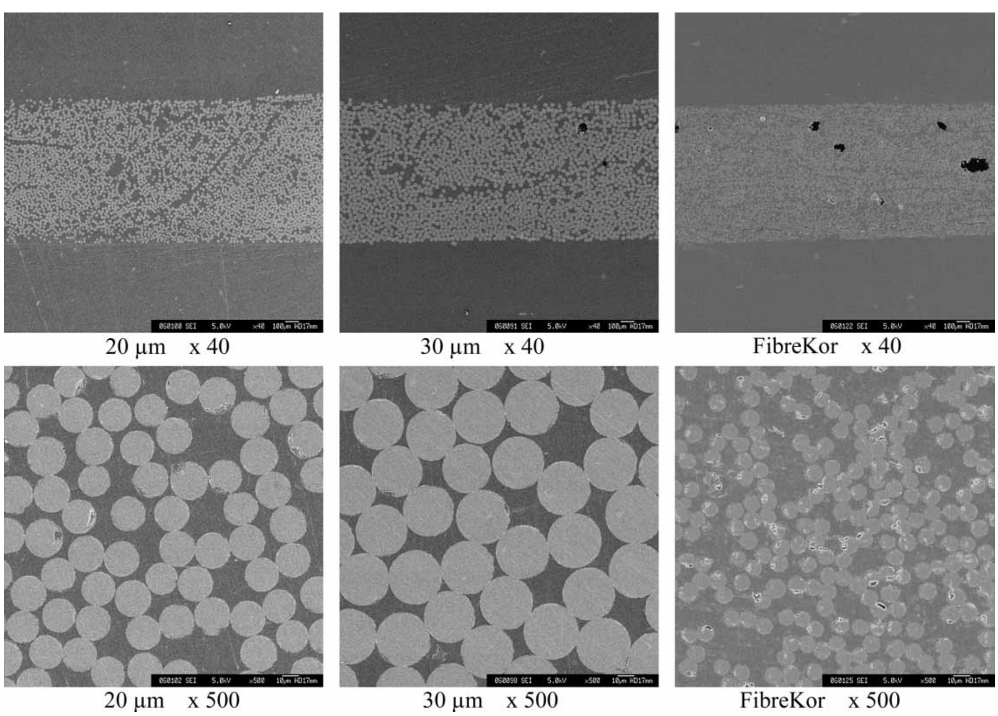


Figure 4. Scanning electron micrographs ( × 40, × 500) showing cross sections of the bar-shaped specimens reinforced with the 20- and 30-μm-diameter fibres FRC and FibreKor.

Table IV. Compressive strength at proportional limit (N) of the maxillary acrylic resin denture reinforced with several reinforcing materials and reinforcing efficiency (times) of the reinforcing material on the denture without reinforcement ($n = 5$)

| | Group | Mean (SD) | Reinforcing efficiency |
|---|---|---|---|
| I. | Bulk | 705.9 (110.3) | 1 |
| II. | 1.0 mm–20 μm | 988.4 (134.0)[a*] | 1.40 |
| III. | 1.5 mm–20 μm | 1175.4 (121.8) | 1.67 |
| IV. | Remanium | 902.6 (111.9)[a] | 1.28 |

*[a]No significant differences ($p > 0.05$).

(28.0 N), which was close to the textbook value (26.2 MPa) [1]. The FS-PL of the denture base resins reinforced with the FRCs was significantly higher than that of the unreinforced resins. The flexural strength of the denture resins (PMMA) ranged from 78 MPa to 92 MPa [1] and of the light-cured FRCs from 132 MPa to 764 MPa [39–42]. It is therefore reasonable to conclude that the FRCs had a reinforcing effect on the denture base resin.

A previous study [42] revealed that the flexural strength of the FRC increased with increasing fiber diameter. The values for the 20-, 25-, 30- and 45-μm-diameter fibers (ranging from 664 MPa to 700 MPa) were significantly higher than those for the 16-μm-diameter fibers or less, which indicated that better flexural properties were found for the 20 to 30-μm-diameter glass fibers in the FRC materials [42]. Therefore, the FS-PL of the bar-shaped acrylic resin specimens reinforced with FRC containing the 20- and 30-μm-diameter glass fibers was investigated in this study. It was found that there was no significant difference between the 20 μm and the 30 μm specimens, which was similar to the results for the FRC materials.

The palatal plate of a maxillary complete acrylic resin denture is generally about 2 to 3 mm thick, and 1.0 to 1.5 mm thick or 1.0 to 1.5 mm diameter metal reinforcements have been used in them [2–5]. Hence, three thicknesses of the polymerized FRC reinforcing materials (0.5, 1.0 and 1.5 mm) were tested in this study. In a preliminary study on the width of the polymerized FRC reinforcing materials, the FS-PL of denture base resin reinforced with the 3.0-mm-wide and 1.0-mm-thick FRC (43.2 ± 2.5 N) was significantly lower than that with the 5.0-mm-wide and 1.0-mm-thick FRC (50.1 ± 3.0 N). Therefore, a width of 5.0 mm was chosen. As a result, the thickness of the FRC reinforcing material significantly affected the FS-PL of the denture base resin. In fact, the FS-PL of the denture base reinforced with the FRC increased with the increasing thickness of the FRC reinforcing material. It is logical that the presence of a thicker reinforcing material increases the strength of the reinforced denture base resin.

The FS-PL of a denture base resin reinforced with the 1.0-mm-thick FRC was higher than that with the FibreKor (1.0 mm thick). The scanning microscopic views of the reinforcement cross sections show the differences in the diameter of the glass fibers and the distribution of the glass fibers in the matrix. Furthermore, there was a difference in the fiber content of FibreKor and the novel FRCs of approximately 44% and 62–63%, respectively. Moreover, the flexural strength of the FRC was higher than that of FibreKor [42]. Apparently these differences affected the FS-PL of the reinforced bar-shaped specimens.

In this study, three types of metal wire were used for reinforcement; they were all 1.0 mm thick or 1.0 mm diameter. Metal is considered to be a stronger reinforcing material for an acrylic resin denture [2]. The fabrication of superior FRC reinforcing material to reinforce acrylic resin dentures was the goal of this project, but little is known about comparing FRC material and metal wire as reinforcing materials in an acrylic resin denture. The Clasp Wire affected the reinforcement of the acrylic resin denture base very little. According to the data found in the literature, the reinforcing efficiency of metal reinforcements ranged from 1.63 to 1.69 [3,4] and of glass fiber from 1.3 to 6.6 [18,20–22,25,26]. The values of the glass fiber reinforcements varied because the experimental conditions were different from those found in this study; however, the values for the metal reinforcements were close to those of Remanium and Bar Wire. With regard to the 1.0-mm reinforcing materials, the FS-PL of the bar-shaped denture base resin reinforced with the FRC approximately equaled Remanium and Bar Wire. The reinforcing efficiency of the FRC was about 1.8 (times higher than the FS-PL of the bulk material), and Remanium and Bar Wire were 1.76 to 1.84, respectively. Furthermore, the 1.5-mm-thick FRC surpassed the FS-PL of the bar-shaped specimens of Remanium and Bar Wire with a reinforcing efficiency of approximately 3.2. Therefore, the research hypothesis of this study was confirmed.

It is reported that the most common types of damaged dentures are maxillary complete dentures, which typically fail due to fatigue. A midline fracture generally originates at the notch between the two central teeth and extends partially or completely through the denture base [43]. In the clinical study [28], emphasis was placed on the importance of correct positioning of the PFR (partial fiber reinforcement) on the tension side during mastication, perpendicular orientation to the possible fracture line, length of the PFR, and accurate laboratory technique. With regard to the maxillary complete denture, clinical studies [27,28] recommended that the PFR should be placed on the side of the denture affected by tensile stress during mastication, i.e. close to the ridge lap surfaces of the incisors. Likewise, in this study, the reinforcing material was embedded in the denture base resin in the doughy state and placed under the ridge lap surfaces of the teeth from the left 2nd premolar to the right 2nd premolar of the maxillary complete denture. The results indicated that there was no significant difference of the CS-PLs of the maxillary complete dentures reinforced with the 1.0-mm-thick FRC and the Remanium; the denture reinforced with the 1.5-mm-thick FRC was significantly higher. The results of the CS-PL of the reinforced maxillary complete dentures were almost identical to those for the reinforced bar-shaped specimens. Moreover, the reinforcing efficiency of the FRC on the maxillary complete dentures was 1.40–1.67. Clinically, bending a metal wire reinforcement like Remanium or Bar Wire is generally difficult, but handling a light-cured FRC material is not complex. Thus, it is suggested that if there is space for a 1.0 to 1.5-mm-thick and 5-mm-wide FRC to reinforce a denture base, the FRC reinforcing material will be better.

This study indicated that unidirectional glass-fiber-reinforced composite was useful as a reinforcing material for acrylic denture base material.

## Conclusions

1. The unidirectional glass-fiber-reinforced composite had a reinforcing effect on the flexural strength at the proportional limit of a denture base resin.
2. The flexural strength at the proportional limit of a denture base resin reinforced with the 1.0-mm-thick FRC was similar to that for Remanium and Bar Wire without the clasp wire. The 1.5-mm-thick FRC surpassed the proportional limit of the metal reinforcing materials.
3. The reinforcing effect of the fiber-reinforced composite on the compressive strength at the proportional limit of the maxillary acrylic resin complete denture was similar to the effect on the flexural strength at the proportional limit of the bar-shaped denture base resin.

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