

ORIGINAL ARTICLE

Reinforcing effect of glass fiber-reinforced composite reinforcement on flexural strength at proportional limit of a repaired denture base resin

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Abstract

Objective: This study evaluated the reinforcing effect of glass fiber-reinforced composite (FRC) reinforcement on flexural strength at the proportional limit (FS-PL) of a repaired denture base resin.

Materials and methods: Repaired denture base resins reinforced with metal and with FRC reinforcement, and that without reinforcement were tested. The ultimate flexural strength, the FS-PL and the elastic modulus of repaired denture base resins were tested. The joint efficiency (times) of the repaired denture base resins on the intact denture base resin was evaluated.

Results: The repaired denture base resins reinforced with metal reinforcement and with FRC reinforcement had significantly higher ultimate flexural strength than the repaired denture base resin without reinforcement ($p < 0.05$) and were not significantly different from each other ($p > 0.05$). The FS-PL of a repaired denture base resin reinforced with the FRC reinforcement was similar to that with the metal reinforcement ($p > 0.05$), and these were significantly higher than the FS-PL of a repaired denture base resin without reinforcement ($p < 0.05$). The elastic modulus of the repaired denture base resin reinforced with the FRC reinforcement was significantly lower than that with metal reinforcement ($p < 0.05$) and was significantly higher than that without reinforcement ($p < 0.05$). The joint efficiency of the FRC reinforced specimen was 0.98.

Conclusion: The FRC reinforcement had a reinforcing effect on the FS-PL of a repaired denture base resin.

Keywords

Elastic modulus, joint efficiency, repaired denture base resin, ultimate flexural strength

History

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Introduction

Since the mid-1940s, the majority of denture bases have been fabricated using polymethyl methacrylate resins, and heat-activated resins are used in the fabrication of nearly all denture bases.[1] These materials are typically low in strength, moderately flexible, brittle on impact, and fairly resistant to fatigue failure.[2] The fracture of acrylic resin dentures is an unresolved problem in prosthodontics.[3] Hargreaves [4] reported that 68% of dentures had broken by the end of three years after placement. Yli-Urpo et al.[5] found that 28% of dentures underwent repair during the first year of use and 39% required repair during the first three years of use.

Metal wire reinforcement has conventionally been used to strengthen acrylic resin dentures in order to prevent clinical fracture. Recently, glass fibers have been employed to reinforce acrylic resin dentures so as to prevent a denture fracture. Regarding glass fiber reinforcement, the denture base can be reinforced with fibers in two ways: the entire denture base can be reinforced with a fiber weave [total fiber

reinforcement (TFR)] or a fiber reinforcement can be placed precisely at the weakest region of the denture [partial fiber reinforcement (PFR)].[6,7] If the fiber reinforcement is incorporated in the denture during repair, PFR is the reinforcement of choice because it is easier to handle than TFR.[6] In addition, PFR can prevent recurrent fractures in acrylic resin dentures.[7]

Metal wire reinforcement[8-13] and glass fiber reinforcement[8,11,12,14-23] for denture base resins have been investigated. With regard to denture repair, some studies investigated metal reinforcement[3,24-26] and glass fiber reinforcement.[7,24-27]

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 to their use.[28] A denture material should have a proportional limit sufficiently high that permanent deformation does not result from the stress applied during mastication.[2] Therefore, the estimation of the proportional limit of a material using its resistance to plastic deformation is of significant clinical value. Several studies have evaluated the resistance of denture polymers to plastic deformation under a flexural load.[28-32] Nevertheless, the flexural strength at the proportional limit (FS-PL) of repaired denture base acrylic resins has not yet been investigated.

It was hypothesized that the glass fiber-reinforced composite (FRC) reinforcement has a reinforcing effect on the FS-PL of a repaired denture base resin. The purpose of this study was to investigate the reinforcing effect of glass FRC reinforcement on the FS-PL of a repaired denture base resin.

Materials and methods

A denture base resin (Acron, GC Corp., Tokyo, Japan, Lot No. (P):1011193, (L):1010272), an auto-polymerized repair resin (Uni-fast III, GC Corp., Tokyo, Japan, Lot No. (P):1012211, (L):1011251), and glass FRC (everStick C&B, GC Corp., Tokyo, Japan, Lot No.: 1207201G) were selected for this study. And 1.0 mm diameter round wire (Sun-Cobalt Clasp-Wire, Dentsply-Sankin K.K., Tochigi, Japan, Lot No. E700370) was used as a control.

A repaired denture base resin reinforced with glass FRC was investigated. As controls, repaired denture base resins reinforced with metal wire reinforcement and without reinforcement were tested, and furthermore, intact denture base resin without reinforcement was investigated.

Repaired denture base resin specimens with reinforcement (none, metal, FRC) were fabricated. Half size specimens were fabricated. The specimens were heat-polymerized and fabricated according to the manufacturer's instructions in gypsum molds with cavities (31 mm long × 10 mm wide × 2.5 mm high). Each specimen was polished with 600-grit SiC paper. The accuracy of the dimensions was verified with a micrometer at three locations for each dimension to within a 0.05-mm tolerance for width and height. Two parts were put in a gypsum mold with cavities (65 mm long × 10 mm wide × 2.5 mm high) at an interval of 3 mm after tinfoil substitute had been applied over it. The denture base resin for the reinforcement space was also cut away in 3 mm wide. Reinforcements were adapted to the reinforcement spaces. The surface of the metal reinforcements (1.0 mm diameter round wire, 30 mm long) were sandblasted with 50 μm grain-sized alumina (Aluminous Powder WA 360, Pana Heraeus Dental Inc., Osaka, Japan) using a grit blaster (Micro Blaster, Comco Inc., Burbank, CA, USA) for 10 seconds at an emission pressure of 0.3 MPa. The nozzle was positioned at a right angle approximately 10 mm from the surface of the metal reinforcement. The sandblasted metal reinforcement was then cleaned in distilled water for 10 min in an ultrasonic cleaner (Branson 2510J-MTH, Branson Ultrasonics Corp., Danbury, CT, USA). Immediately after the cleaned metal reinforcement was dried, a metal conditioner (Alloy Primer, Lot No.:1G0005, Kuraray Medical Inc., Tokyo, Japan) was applied to the sandblasted surface with a sponge pellet. An FRC reinforcement (Figure 1; 1.5 mm diameter round, 30 mm

long) in prepreg state was cured with a light-curing unit (G-light Prima II, GC Corp., Tokyo, Japan) for 3 min. The reinforcement was placed in the reinforcement space. The monomer and polymer of an auto-polymerized repair resin was mixed and then poured into the break and into the reinforcement space carefully until the area to be repaired was filled. After polymerization, the area was polished.

Intact denture base resin specimen without reinforcement was fabricated. The specimen was heat-polymerized and fabricated according to the manufacturer's instructions in gypsum molds with cavities (65 mm long × 10 mm wide × 2.5 mm high). The polymerized specimen was polished with 600-grit SiC paper. The accuracy of the dimensions was verified with a micrometer at three locations for each dimension to within a 0.05-mm tolerance for width and height.

All specimens were stored in 37 °C distilled water for 50 h before testing. Ten specimens were fabricated for each group and all the tests were performed under uniform atmospheric conditions of 23.0 ± 1 °C and 50 ± 1% relative humidity.

The specimens were fractured using a load testing machine (AGS-J, Shimadzu Co., Tokyo, Japan). The ultimate flexural strength, the FS-PL[28-32] and the elastic modulus of the specimens were tested. Each specimen was placed on a 50-mm-long support for three-point flexural testing (Figure 2). A vertical load was applied at the midpoint of the specimen at a crosshead speed of 1 mm/min on a load testing machine.

The ultimate flexural strength (MPa) was calculated according to the following formula:

$$\text{Ultimate flexural strength} = \frac{3Fl}{2bh^2}$$

where F = the maximum load (N), l = the span distance (50 mm), b = the width (mm) of the specimen, and h = the height (mm) of the specimen.

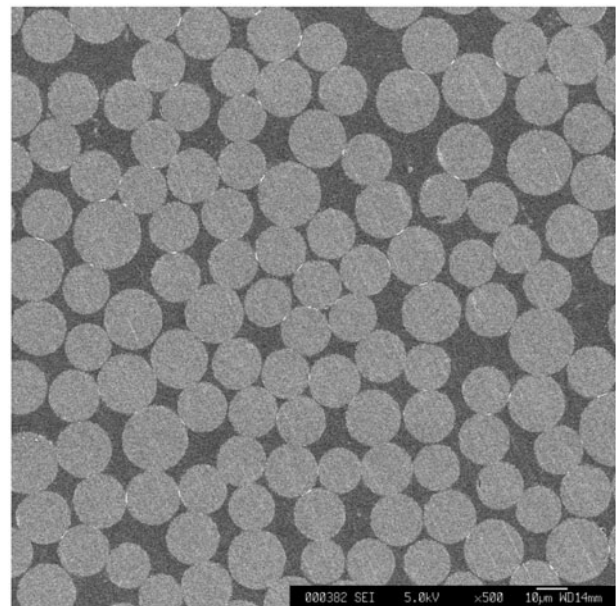


Figure 1. Scanning electron micrograph (500×) of cross section of polymerized FRC reinforcement.

The FS-PL (MPa) was calculated according to the following formula:

$$\text{FS - PL} = \frac{3F_1l}{2bh^2}$$

where F_1 = the load (N) at the proportional limit. The load at the proportional limit was determined from each load/deflection graph.

The elastic modulus (GPa) was calculated using the following formula:

$$\text{Elastic modulus} = \frac{F_2l^3}{4bh^3d}$$

where F_2 = the load (N) at a point in the straight line portion of the load/deflection graph, and d = the deflection (mm) at load F_2 .

The data were analyzed statistically using a one-way analysis of variance (ANOVA) (STATISTICA; StatSoft Inc., Tulsa, OK, USA), and the Newman-Keuls post hoc comparison (STATISTICA) was applied when appropriate (95% confidence level).

The joint efficiency (times) of the repaired denture base resin on the intact denture base resin without reinforcement was calculated using the FS-PL.

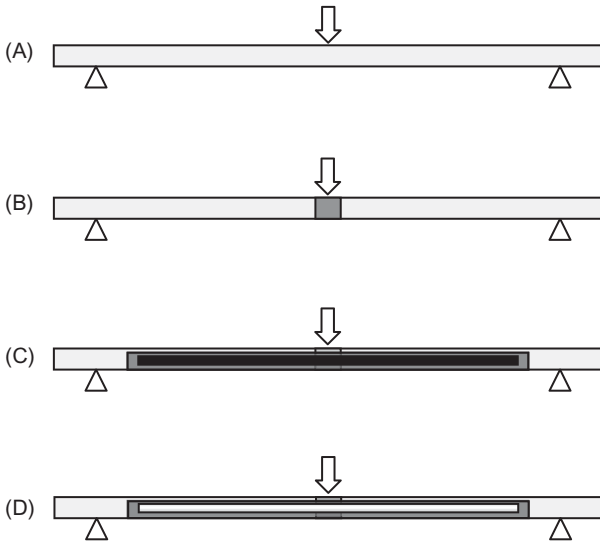


Figure 2. Schematic of specimens. (A) intact specimen, (B) repaired specimen without reinforcement, (C) repaired specimen reinforced with metal wire reinforcement, (D) repaired specimen reinforced with FRC reinforcement.

The fiber content (vol.%) of each glass fiber of the FRCs was determined with an ashing method.[19,33] Five specimens of each FRC were desiccated for 36 h at 37 °C and weighed to an accuracy of 1 mg. The specimens were 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, Göttingen, Germany). The fiber content was calculated according to the following formula:

$$V_g = W_g/\rho_g \div (W_g/\rho_g + W_r/\rho_r) \times 100$$

where V_g = volume percentage (vol.%) of fiber, W_g = weight percentage of fiber, ρ_g = density of the fiber (2.55 g/cm³), W_r = weight percentage of the matrix resin, and ρ_r = density of the matrix resin (1.0 g/cm³).

Results

The one-way ANOVA revealed a significant difference ($p < 0.05$) in the ultimate flexural strength of the condition of denture base resin/reinforcement combination. The repaired denture base resins reinforced with metal reinforcement and that with FRC reinforcement had significantly higher ultimate flexural strength than the repaired denture base resin without reinforcement ($p < 0.05$), and had significantly lower ultimate flexural strength than the intact denture base resin ($p < 0.05$), and were not significantly different from each other ($p > 0.05$) (Table 1).

The one-way ANOVA revealed a significant difference ($p < 0.05$) in the FS-PL of the condition of denture base resin/reinforcement combination. The FS-PLs of the intact denture base, the repaired denture base resin reinforced with metal reinforcement and the repaired denture base resin reinforced with FRC reinforcement were significantly higher than the FS-PL of the repaired denture base resin without reinforcement ($p < 0.05$), and were not significantly different from each other ($p > 0.05$) (Table 1).

The one-way ANOVA revealed a significant difference ($p < 0.05$) in the elastic modulus of the condition of denture base resin/reinforcement combination. The elastic modulus of the repaired denture base resin reinforced with metal reinforcement was significantly higher than that of the others ($p < 0.05$). The elastic moduli of the repaired denture base resin reinforced with FRC reinforcement and the intact denture base resin were not significantly different from each other ($p > 0.05$), and the elastic moduli of the intact denture base and the repaired denture base resin without reinforcement were not significantly different from each other ($p > 0.05$) (Table 1).

Table 1. Mean and standard deviation (SD) of the flexural properties of the repaired denture base resin ($N = 10$).

| Condition of denture base resin | Reinforcement | Ultimate flexural strength (MPa) | Flexural strength at the proportional limit (MPa) | Elastic modulus (GPa) |
|---------------------------------|---------------|----------------------------------|---|--------------------------|
| Intact | None | 82.2 (12.3) | 47.5 (1.6) ^a | 2.9 (0.3) ^{a,b} |
| Repaired | None | 32.9 (6.7) | 27.5 (5.7) | 2.6 (0.2) ^b |
| Repaired | Metal | 62.7 (12.3) ^a | 40.5 (6.7) ^a | 3.8 (0.4) |
| Repaired | FRC | 51.7 (17.1) ^a | 46.6 (17.0) ^a | 3.2 (0.3) ^a |

^a or ^b denotes no significant differences ($p > 0.05$).

Table 2. The joint efficiency (times) of the repaired denture base resin on the intact denture base resin using the flexural strength at the proportional limit.

| Condition of denture base resin | Reinforcement | Joint efficiency (times) |
|---------------------------------|---------------|--------------------------|
| Intact | None | 1 |
| Repaired | None | 0.58 |
| Repaired | Metal | 0.85 |
| Repaired | FRC | 0.98 |

The joint efficiency (times) of the repaired denture base resin reinforced with metal reinforcement was 0.85 and that with FRC reinforcement was 0.98 (Table 2).

Fiber content of the FRC reinforcement (vol.%) was 41.4 ± 0.6 vol.%.

Discussion

The hypothesis of this study was accepted, and the FRC reinforcement had a reinforcing effect on the FS-PL of a repaired denture base resin.

The present study introduced a clinically relevant means to study the strength of the denture base after repair. Repaired denture base resin specimens and intact denture base resin specimens were used. Evaluation of the proportional limit of the repaired denture base material was deemed appropriate because stresses higher than the proportional limit initiate permanent plastic deformation and render the material unusable.[28]

According to the data found in the literature, a heat polymerized denture base resin repaired with an autopolymerized resin showed 39% to 82% decrease in the ultimate flexural strength (load) compared with an intact heat polymerized denture base resin.[3,24,27] Likewise, in this study, the repaired specimen without reinforcement showed 60% reduction in the ultimate flexural strength compared with the intact specimen. It is well known that repaired acrylic resin denture after fracture becomes weak. Therefore, mechanical properties of metal reinforcement[3,24-26] and glass fiber reinforcement[7,24-27] for the repair of acrylic resin denture after fracture have been investigated. In the present study, repaired denture base resin reinforced with metal reinforcement or FRC reinforcement had a significantly higher ultimate flexural strength than the repaired denture base resin without reinforcement, and the tendency was similar to previous studies.[3,7,24-27] From these results, it is indicated that metal reinforcement and FRC reinforcement have the reinforcing effect for the repair of an acrylic resin denture base in the ultimate flexural strength. However, the ultimate flexural strength of the repaired denture base resin reinforced with metal reinforcement, or FRC reinforcement, was significantly lower than that of an intact specimen. Therefore, reinforced denture base after repair, did not reach the ultimate flexural strength of the intact denture base resin in the present study.

With regard to the FS-PL of the reinforced denture base resin, in a previous study,[12] the FS-PL of an acrylic resin bar-shaped specimen reinforced with metal wire reinforcement was similar to the FS-PL of the bulk denture base resin

specimen, and the FS-PL of an acrylic resin bar-shaped specimen reinforced with FRC reinforcement was higher than the FS-PL of the bulk denture base resin specimen. In the present study, the FS-PLs of the repaired denture base resin reinforced with FRC reinforcement and the repaired denture base resin reinforced with metal reinforcement were significantly higher than the FS-PL of the repaired denture base resin without reinforcement, and were not significantly different from each other. Moreover, these were not significantly different from the FS-PL of the intact denture base resin. From the previous study and the present study, the results may be due to difference in the strength of base material; i.e. the strength of a bulk denture base resin is higher than the strength of a repaired denture base resin. Therefore, metal reinforcement and FRC reinforcement showed a reinforcing effect for the repaired denture base resin lower than the bulk denture base resin in the FS-PL.

The elastic moduli of the repaired denture base resin reinforced with metal reinforcement and the repaired denture base resin with FRC reinforcement were significantly higher than the elastic modulus of the repaired denture base resin without reinforcement. These results were reasonable, because a reinforcement material was stiffer than a denture base resin and was combined into the denture base resin. As a result, the reinforced denture base resin after repair became stiffer than the unreinforced denture base resin after repair.

The joint efficiency of the repaired denture base resin reinforced with metal reinforcement was 0.85 times and that with FRC reinforcement was 0.98 times. Namely, the repaired denture base resin reinforced with metal reinforcement showed 15% decrease in the FS-PL compared with the intact denture base resin specimen, and the FS-PL of the repaired denture base resin reinforced with FRC reinforcement recovered to the FS-PL of the intact denture base resin. The result seemed to indicate that FRC reinforcement generally tended to be effectively compared to metal wire reinforcement for the repair of an acrylic resin denture base in the FS-PL. This finding may be due to the chemical bonding of the reinforcement to the acrylic resin, while the metal reinforcement did not bond completely to the acrylic resin. Conversely, FRC reinforcement was incorporated into the denture base; as a result, the reinforced denture showed higher joint efficiency.

Applying the results of the present study clinically, repair of an acrylic resin denture after fracture significantly decreased its resistance to plastic deformation. In order to improve the resistance to plastic deformation, metal reinforcement and FRC reinforcement had a reinforcing effect for repaired acrylic denture base resin after fracture. Moreover, the elastic modulus of the reinforced denture resin after repair caused stiffness, which is clinically acceptable. Especially, the joint efficiency of the repaired denture base resin reinforced with FRC reinforcement showed 0.98 times, and it means that the FS-PL of repaired denture base resin reinforced with FRC reinforcement was close to the FS-PL of intact denture base resin. The repaired denture base should be preserved for optimum strength. Therefore, FRC reinforcement is preferable to metal reinforcement for a repaired acrylic resin denture. FRC is a composite material and its properties may be affected by water sorption. In the present study, flexural

properties of repaired denture base resins were evaluated after 50-h water immersion. However, there are various conditions for an acrylic resin denture in the oral cavity; the moist environment, the temperature changes and the dynamic loading caused by biting force. Thus, it will be necessary to estimate the durability of repaired denture base resins.

Conclusions

Under the conditions of the present experiment, the following conclusions may be drawn:

- (1) The repair of the fractured denture base material with the autopolymerizing resin significantly decreased its resistance to plastic deformation.
- (2) The resistance to plastic deformation of the repaired denture base reinforced with the glass FRC emulated the resistance to plastic deformation of the intact denture base resin material.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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