



Improving the mechanical properties of fiber-reinforced acrylic denture-base resin

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ABSTRACT

This study evaluated the effects of different oligomers and silane-treated filler on the bending strength, bending modulus, compressive strength and compressive modulus of a fiber-reinforced acrylic resin for use in denture bases. The results showed that the investigated oligomers only improved the bending modulus. Using an inorganic filler treated with two types of silanes – γ -methacryloxypropyltrimethoxy silane and triethoxyvinyl silane – considerably improved the mechanical properties of the fiber-reinforced acrylic resin except for the bending strength, with triethoxyvinyl silane being more effective than γ -methacryloxypropyltrimethoxy silane. The improvement of the mechanical properties of fiber-reinforced acrylic resin is the incorporation of triethoxyvinyl silane-treated filler.

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1. Introduction

Acrylic resin is the main commercial plastic used in denture fabrication due to its esthetics, ease of manipulation and low cost, even though it is poor at resisting uneven masticatory forces and being dropped [1,2]. Although some parts of the removable denture have been replaced by a cast metal plate, the associated fabrication requires expensive equipment and the dentures are difficult to manipulate [3–5]. The incorporation of fibers into the resin appears to be a good approach for enhancing the strength of removable dentures [6–9]. Although continuous fibers can provide superior reinforcement over shorter fibers, they are difficult to place in the correct position in the denture [10]. In our previous study, we incorporated short-length (6-mm-long) randomly orientated polyester fibers as a resin strengthener [11]. This increased the impact strength several-fold but had little effect on the bending strength and also considerably decreased the surface hardness.

Composite resin was developed by Bowen more than 40 years ago [12,13]. New techniques and compositions have improved its mechanical properties [14–16], especially in the last two decades with the development of a product containing composite resin and glass ionomer cement (compomer restorative material), which has been shown to exhibit enhanced mechanical properties in clinical use [17,18]. In the present study we investigated whether the incorporation of composite resin into fiber-reinforced resin can improve the mechanical properties of denture-base materials.

Restorative composite resin comprises silane-treated fillers and resin that serves as a matrix material [19]. Most such resins are bifunctional oligomers that have two polymerizable double bonds in each molecule. Polymerization results in the formation of numerous cross-links to produce a three-dimensional intertwined structure that exhibits improved craze resistance [20,21]. The filler is treated with various silane coupling agents to achieve good bonding strength with the resin [22].

The main purpose of this study was to elucidate the effects of different types of oligomers and silane-treated fillers on the mechanical properties of fiber-reinforced acrylic denture-base resins. The other aim was to determine the most appropriate combination for strengthening experimental composite resins.

2. Experimental

2.1. Materials

The materials used in this experiment included three types of bifunctional oligomers: 2, 2-bis [4(2-hydroxy-3methacryloxy-propyloxy)-phenyl] propane (Bis-GMA), triethylene glycol dimethacrylate (TEGDMA) and urethane dimethacrylate (UDMA). We also tested two types of silane coupling agents: γ -methacryloxypropyltrimethoxy silane and triethoxyvinyl silane. Furthermore, one type of polyester fiber (IW71, Allied, USA) and one type of inorganic filler (SiO₂ powder with an average particle size of 12.83 μ m) were used to test the mechanical properties of denture-base acrylic resin (Acron GC, Japan).

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2.2. Methods

2.2.1. Filler silanation procedure

SiO₂ was treated according to the manufacturer's instructions by preparing a 95% ethanol solution and adjusting the pH value to 5 with acetic acid. Silane was added by stirring to yield a final concentration of 2%. The solution was allowed to sit for 5 min for hydrolysis and silanol formation. Filler particles were silylated by stirring them in the solution for 2 min and then decanting the solution onto filter paper. The particles were rinsed twice with ethanol and the silane layer was cured for 10 min at 110 °C. The proportion of silane was calculated using the following equation: amount of silane (g) = [amount of filler (g) × surface area of filler (m²/g)] / (minimum coating area of silane coupling agent).

2.2.2. Preparation of the mixed monomer

Oligomers (Bis-GMA, TEGDMA, and UDMA) were mixed at various percentages (4%, 20%, 40%, 60% and 80%; by weight) with Acron resin monomer under electric mixing with an egg mixer for 10 min in a closed glass container.

2.2.3. Preparation of the tested specimens

Based on the method that we described previously [11], polyester fibers were cut to a length of 6 mm without surface treatment. The weight percentage of filler added was based on the measured weight of premixed resin powder and not on the combined powder and liquid or mixed resin weight. Two gypsum molds (70 × 20 × 15 mm³) were prepared using dental flasks and the acrylic resin powder and liquid were mixed at a ratio of 2:1 (w/w) with fibers or filler so as to avoid changing the polymerization reaction. Fibers were incorporated at a random spatial orientation into the acrylic resin at a concentration of 3 wt% in 150-ml plastic beakers using an electric mixer for 1 min. Thirty minutes later, the mixtures were packed into the molds and the excess resin was removed with a presser on trial packing. The flasks were fixed with clamps and cured in a 55 °C water bath for 15 h, then stored at 90 °C for 1 h, and finally cooled on a bench at room temperature. Four series of specimens were prepared: (1) acrylic resin blocks with fibers, (2) fiber-reinforced acrylic resin made with Acron monomer containing bifunctional oligomer, (3) fiber-reinforced acrylic resin containing silanated filler, and (4) fiber-reinforced acrylic resin containing silanated filler cured with a monomer mixture.

2.2.4. Testing methods

A resin block of each specimen was prepared according to ISO specification No. 1567 and then cut into five 65 × 10 × 2.5 mm³ bar specimens. After being immersed in a 37 °C water bath for 48–52 h, the three-point bending strengths of these blocks were tested using a material testing machine (Micro350, Testometric, UK) (Fig. 1) with a crosshead speed of 5 mm/min, the two supporting points separated by 50 mm and the load applied by a centrally located rod until the sample broke. The bending strength was calculated as $BS = 3PL/2bd^2$, where BS is the bending strength, P is the applied pick load, L is the support span length, b is the sample width and d is the sample thickness. A mean value was calculated for the five specimens. The bending modulus was calculated as $BM = PL^3/4Dbd^3$, where BM is the bending modulus and D is the deformation. The mean value was calculated for the five specimens.

The compressive strength was tested empirically based on our previous experience in fabricating the test samples. Another resin block of each specimen was cut into five 4 × 4 × 8 mm³ cubic pillars and tested for compressive strength under a crosshead speed of 2 mm/min on the same testing machine. The compressive strength was calculated as $CS = P/A$, where CS is the compressive



Fig. 1. Micro350, Testometric, UK.

strength, P is the applied pick load and A is the area (4 × 4 mm²). The mean value was calculated for the five specimens. The compressive modulus was calculated as $CM = CS/\text{strain}$, where CM is the compressive modulus, CS is the compressive strength and Strain is the deformation divided by the original height (8 mm). The mean value was calculated for the five specimens.

Statistical analyses were performed with SAS 8.02 (Microsoft, USA). Means and standard deviations were used to describe the data for each property. Two-sample t -tests were used to assess differences in mechanical properties between the baseline material and the various combinations of acrylic resin, filler, monomers and silanated fillers. Statistical tests were two-tailed, and the significance level was set at $p < 0.05$. Only significant changes are described here.

3. Results and discussion

3.1. Fiber-reinforced resin made with various mixtures of monomers

The mechanical properties of fiber-reinforced resins made with various mixtures of monomers are listed in Table 1. The additives did not significantly improve the bending strength of any of the materials. In fact, when the loading percentage was higher than 60 wt%, the bending strength was inferior to Acron with fiber (1121.0 ± 60.8 kg/mm², mean ± standard deviation). The bending moduli of most of the materials (from 2740.2 ± 114.2 kg/mm² to 4025.6 ± 125.4 kg/mm²) were significantly higher than that of Acron with fiber (2716.7 ± 226.5 kg/mm²). The additives did not significantly improve the compressive strength or compressive modulus. Among the three oligomers, Acron resin monomer mixed with 60 wt% Bis-GMA exhibited the highest bending modulus (4025.6 ± 125.4 kg/mm²), but it had lower bending strength (843.1 ± 44.9 kg/mm²) and compressive strength (12.5 ± 0.4 kg/mm²). Acron monomer mixed with 4 wt% UDMA showed the highest compressive strength (13.7 ± 0.5 kg/mm²), but it had lower compressive modulus (87.1 ± 1.7 kg/mm²). Based on the four values of each tested group, we selected Acron monomer mixed with 20 wt% TEGDMA as the best material for the subsequent experimental procedures, since it generally exhibited the highest strength values: bending strength of 1127.8 ± 43.9 kg/mm², bending modulus of 3168.4 ± 194.8 kg/mm², compressive strength of 13.3 ± 0.4 kg/mm² and compressive modulus of 86.7 ± 2.8 kg/mm².

We found that Acron monomer mixed well with each oligomer at the various percentages used. However, the mixture of resin

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