

Evaluation of the Effect of ZrO₂ Nanoparticles and Glass Fibers on the Shear Bond of Repaired Heat-Cured PMMA

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Abstract

Background There has been an increasing demand for incorporating reinforcement materials to increase the strength of denture base acrylic material. **Objectives** To evaluate the effect of incorporating ZrO₂ nanoparticles and E.glass fiber on the shear bond strength of repaired heat-cured acrylic. **Materials and Methods** Thirty repaired heat-cured specimens were fabricated, and ten specimens from the control group did not receive any addition, for the two test groups, ZrO₂ nanoparticles and E-glass fiber at 2% concentration were added (PMMA+2%ZrO₂ nanoparticles group and PMMA+2%glass fibre group). The shear bond strength was measured. **Results** The results showed the maximum value for the shear bond strength test recorded by adding 2%ZrO₂ nanoparticles while the control group recorded the minimum value. **Conclusion** The maximum shear bond strength of repaired heat-cured acrylic could be achieved by the addition of a 2% ZrO₂ nanoparticles group, the addition of 2% glass fiber enhanced the shear bond.

Keywords: Shear bond strength; nano ZrO₂; glass fiber; repair; heat-cured acrylic.

Introduction

The dental field has been using polymethylmethacrylate (PMMA) for a long time due to its satisfactory operating qualities, efficiency in processing, perfect fit, stability within the oral cavity, excellent color constancy, better aesthetics, and use of low-cost apparatus. However, it may have some inferior mechanical qualities despite these benefits. Its inadequate impact strength, fatigue resistance or manufacturing transversal strength could cause fractures in function (Zafar,

2020; Raszewski et al, 2021; Kaur and Thakur, 2022). The successful completion of PMMA denture repair is dependent on several factors, including the reinforcements and adhesive used, the mixture of denture base resin, the surface treatment, and the repair components (Gad et al, 2019; Kumar et al, 2019; AlQahtani and Haralur, 2020). Acceptable dimensional stability with color matching, ease of manipulation, sufficient strength, and cost-effectiveness are all desirable qualities in denture repair materials. Multiple

attempts have been indicated by researchers to improve PMMA resins to enhance both their mechanical properties and the strength of the connection between the repaired materials and the traditional heat-cured denture base resin (Quassem et al., 2019; Gad et al, 2020). Zirconia (ZrO_2) nanofiller is one of the nanomaterials incorporated with polymer due to its exceptional biocompatibility and white color with less susceptibility to change in appearance (Gad et al, 2018; Mutar and Mahdi, 2019; Abdellah et al, 2020). Several fiber reinforcements including nonimpregnated polyethylene fibers were available, light polymerized monomer-impregnated glass fibers, porous polymer pre-impregnated glass fiber, and light polymerized monomer polymer-impregnated glass fiber, had been added to the denture base polymer (Ismail and Muklif, 2015; Gad et al, 2017; Apimanchindakul et al, 2022). The main factors attracting the glass fiber reinforcement are its high mechanical qualities, excellent appearance, and biological biocompatibility (Goiato et al, 2013; Abdul-Majeed and Hummudi, 2019; Al-Thobity, 2020). Various kinds of glass fibers were launched including continuous threads resembling woven sheets, stick net forms, loose sticks, and short rod glass fibers, these were applied to reinforce dental polymers (Yuliharsini et al, 2019; Abushowmi et al, 2020; Schauerperl et al, 2023). The present study was designed to evaluate the shear bond strength of repaired heat-cured acrylic resin after the addition of 2% of zirconia oxide (ZrO_2) nanoparticles and 2% of E-glass fibers.

Materials and Methods

1. Sample grouping

Thirty repaired specimens were divided into three main groups, ($n=10$) according to the reinforcement material that had been added to the repaired heat-cured acrylic,

1. The control group: the heat-cured acrylic repaired without additional reinforcement material (100% PMMA).
2. PMMA+2% ZrO_2 group: the heat-cured acrylic

repaired with the addition of 2% zirconium oxide nanoparticles (98% PMMA)+(2% ZrO_2).

3. PMMA+2% glass fiber group: the heat-cured acrylic repair with the addition 2% short E-glass fiber (98% PMMA)+(2% glass fiber)

2. Specimens preparation

A circular silicon mold measuring $15(\pm 0.2)$ mm in diameter and $3(\pm 0.2)$ mm in thickness was used to prepare the wax specimens that were flaked using dental stone, Figures (1) and (2). Heat-cured acrylic resin (Superacryl. Spofa Dental, Kerr company, Czech Republic) which is mixed according to the manufacturer's instructions 22g/10ml (powder/liquid ratio), packed and cured in a water-bath curing unit for 2 hours at $95^\circ C$. All denture base specimens were finished with abrasive silicon carbide paper. The specimens were cleaned in an ultrasonic apparatus bath (Crest Ultrasonic Crop) for 1 minute to remove contaminated particles and then were randomly divided into three main groups (control group and two experimental groups).

3. Bonding procedure

For bonding procedures, a special silicone mold with two circular holes and one cubic hole is used to achieve the required bonding area dimensions. The first hole $15(\pm 0.2)$ mm in diameter and thickness of $3(\pm 0.2)$ mm was designed for placement of the denture base specimen, while the center hole was $5(\pm 0.2)$ mm in diameter and $2(\pm 0.2)$ mm in height for boundaries the area of the repaired surface (Sarac et al, 2005; Aimjirakul et al, 2023). Each denture base specimen is placed in position, and the central hole is filled with wax using a silicone mold. The traditional flasking and wax removal techniques were completed. After all the base specimens were packed and deflashed, the bonding area was shaved. For the control group, the denture base specimen surface was treated by applying monomer for 3 minutes before packing the repaired surface (Abushowmi et al, 2020; AlQahtani and Haralur, 2020) and then packed again as repaired specimen surface but

with heat-cured acrylic with no reinforcement additives (Superacryl, Spofa Dental, Kerr company, Czech Republic) then finally finished and polished

4. Reinforced repaired heat-cured acrylic

In the experimental groups, the repaired heat-cured resin was reinforced by adding 2% oxide or fiber materials. The additional reinforced material was zirconium oxide ZrO₂ nanoparticles (Changsha Santech, China) in one experimental group and discontinuous short E-glass fibers with a diameter of 13 μ m and 3000 μ m in length were added in the other experimental group. To achieve an equal and constant dispersion of reinforcement particles throughout the resin polymer powder mixture, a magnetic stirrer machine (JOANLAB, China) was used for 30 minutes at 450 rpm (Aimjirakul et al, 2023). Then, the prepared mixture powder was mixed with monomer packed, deflasked, and finished as the control group. A cubic hole was filled with cold-cured acrylic to create a resin block that helps hold the specimen during shear bond test measurements.

5. Shear bond testing procedure

The specimen was fixed to the Instron universal testing machine (Laryee WDW-50, China) in the lower part of the jig testing machine while the acrylic block was positioned horizontally to ensure that the test blade's long axis was parallel to the junction of the denture base and repaired resin interface, Figures (3). The shear load was applied at a crosshead speed of 1mm/min with a 50 N load cell (Ismail et al, 2021; Aimjirakul et al, 2023). During the test, the machine was linked to a computer program that showed the load failure fracture force automatically. By dividing the load (N) by the bonded area (mm²), the shear bond strength was computed in MPa.

6. Mode of failure

The fracture specimens were examined after de-bonding to determine the mode of failure

under digital microscopy (Dino-Lite, Taiwan) at a magnification of 50x. Failure modes were classified as adhesive (if no remnants of repair heat-cured acrylic were found in the denture base acrylic), cohesive (if fractures occurred within the repaired acrylic or denture base acrylic), or mixed (if remnants of repaired acrylic were found in the denture base surface), Figure (4).

7. Scanning electron microscope

One specimen was taken randomly from each group, cleaned for five minutes in an ultrasonic cleaning bath, and allowed to air dry to assess the effect of reinforcement material on the surface of each denture base material. Afterwards, 600-grit silicon carbide paper was used to level the restored surface (Bharadwaj, 2018; Yuliharsini et al, 2019; Hussain et al, 2020). A field-emission scanning electron microscope (SEM) (Czech Republic, Netherlands) was used to examine the repaired surface after being sputtered coated with gold. X2000 magnification photos were acquired using a 20 kV accelerating voltage, Figure (5).

8. Statistical Methods

The shear bond strength results were analyzed using one-way ANOVA. Descriptive statistics were applied to calculate the mean, standard deviation, maximum, and minimum values.

Results

Tukey HSD was used to compare the tested groups, table (1) shows there were significant differences between the study groups ($P < 0.05$). Bar chart as in Figure (6) showing the mean values of the shear bond of all studied groups. The results indicated that the highest mean value of the shear bond obtained in PMMA+2% ZrO₂ of 20.121($\pm$ 1.309), while the lowest mean value was obtained in the control group 12.110($\pm$ 1.240). The mean value of the shear bond in group PMMA+2% glass fiber was 14.096($\pm$ 1.385).

Table (1): Inferential statistic by Tukey(HSD) test for studied groups

Groups		Mean Difference	P-Value
PMMA	PMMA+2% ZrO ₂	-8.0110*	.000(s)
	PMMA+2% Glass Fiber	-1.9860*	.006(s)
PMMA+2% ZrO ₂	PMMA+2% Glass Fiber	6.0250*	.000(s)



Figure (1): Silicone mold of the specimen.



Figure (3): Specimen under Shear bond test.

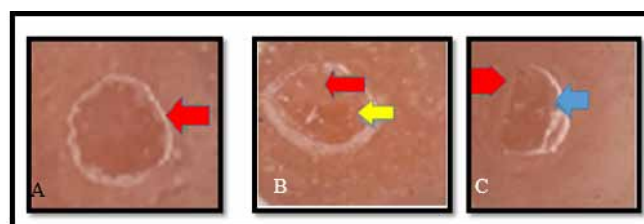


Figure (4): Images under dental light at 50x magnification showing a mixed failure at the bonding interface between the PMMA and reinforced heat-cured acrylic resin, A, adhesive failure, (b & c), mixed failure, Red arrow: adhesive failure, Yellow arrow: cohesive failure of denture base acrylic resin; C, cohesive failure of reinforced repaired heat-cured PMMA.

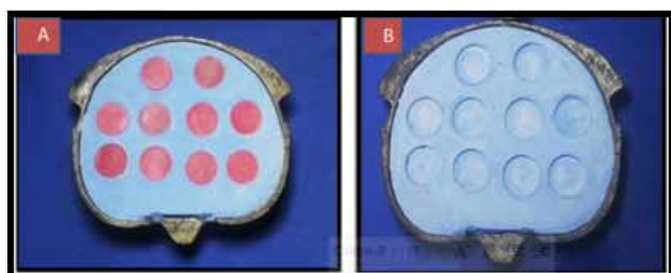


Figure (2): A, Flasking of wax specimens; and B, The specimens mold after wax elimination.

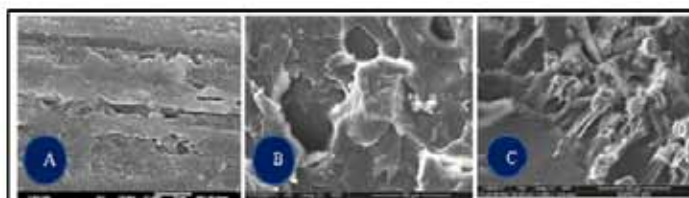


Figure (5): SEM images (x2000) showing the failure at the bonding interface, A, control group; B, PMMA+2% ZrO₂ nanoparticles; C, PMMA+2% glass fiber.

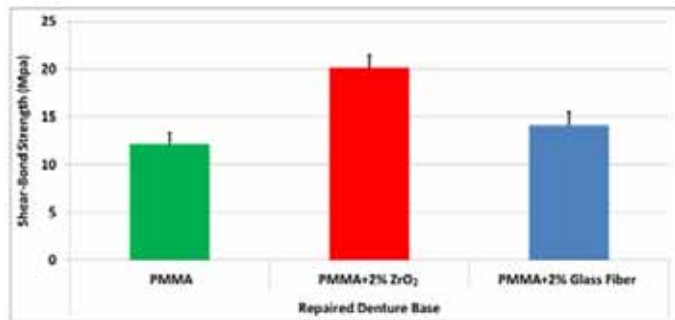


Figure (6): Bar chart showing the mean values of the shear bond of all tested groups.

Discussion

There are numerous uses for different types of polymers reinforced with fibers and nanoparticles (Gad et al, 2017). Research has studied polymers reinforced with various fibers or nanoparticle types to overcome the single type of reinforcement agent (Ismail and Muklif, 2015). Glass fibers are also biologically acceptable and have excellent mechanical qualities. Furthermore, their use with the PMMA denture base material enhances its mechanical characteristics (Goiato et al, 2013). This research was performed to assess the shear bond strength of the repaired heat-cured acrylic after adding ZrO₂ and glass fiber of 2% to PMMA heat-cured resin. For the ZrO₂ nanoparticles, the formation of cross-links or supramolecular bonding that covers or saves the nanofiller and prevents crack propagation causes high shear bond strength between the nanofiller and resin matrix. Complete wetting of the nanofiller by resin also contributes to an increase in shear bond (Ismail et al, 2021). The presence of uniform nanoZrO₂ particles in the resin matrix, Figure (5-B) demonstrated their beneficial effect on enhancing the shear bond strength. The nanoparticles also had a high specific surface area, which allowed them to dissipate energy and possibly improve the strength (Gad et al, 2019), they reinforced the PMMA with ZrO₂ nanoparticles, and they concluded that the addition of ZrO₂ nanoparticles improved the flexural strength and impact strength. In terms of

glass fiber, the strength of the repaired acrylic resin is increased by the addition of E-glass fiber, which acts as a reinforcement agent. By evenly distributing the load throughout the material it seems that these fibers prevent cracks and fractures from occurring. Compared to other fiber kinds, glass fibers have the important advantage of providing superior mechanical enhancement and aesthetics (Hussain et al, 2020) Research demonstrates that the flexural strength, toughness, and Vickers hardness of the denture base were all increased by the addition of glass fiber (Quassem et al, 2019; Abdul-Majeed and Hummudi, 2019; Abushowmi et al, 2020).

The assessment of bonding performance has historically been based on the mechanism of failure; adhesive failure has been considered the least acceptable, followed by cohesive and compared to ZrO₂ nanoparticles, the glass fiber collected as bundles figure (5-C) had decreased adherence to resin (Gad et al, 2019). The addition of 2% nano ZrO₂ or glass fiber significantly increased the shear bond strength in comparison to the control group.

Conclusions

Within the present study limitations, repaired acrylic with an addition of 2% nano ZrO₂ particles or 2% glass fiber increase the shear bond strength. Yet, the addition of 2% nano ZrO₂ particles increased the shear bond strength more than the 2% of glass fiber.

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