RESEARCH PAPER

Effects of Zirconium Oxide Nanofillers on Transverse and Impact Stresses of Heat-Cure Acrylic Resin Polymerizations

Ibrahim Hamad Alfahdawi

College of Dentistry, University of Al Maarif, Al Anbar, Iraq

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ABSTRACT

This study investigates the effects of diverse concentrations of zirconium oxide nanofiller powders (2%, 4%, 6%, and 8%) on the transverse and impact strengths of heat-cure polymer resin polymerization. Our approach's novelty lies in using a novel method developed using pure polymethyl methacrylate. Powder samples of zirconium oxide in various concentrations were blended with hot-cured acrylic resin, which is treated with ideal conditions (L/P) rate of about 1: 3 (v/v), traditional packing method, and short curing cycle. Under two heating program of about 74 °C (90 min) and 100 °C (30 min), polymethyl methacrylate (PMMA) specimens with dimensions of 65× 10× 2.5 mm for transverse strength and 60× 7× 4 mm for impact strength were evaluated. Values for impact stress (J) and transverse stress (MPa) were gathered, tabulated, and statistically analyzed. ANOVA and Tukey's tests were used to assess the range for the experimental samples. The addition of ZrO_2 nanofillers significantly increased PMMA 's transverse and impact strengths, suggesting practical applications for denture base materials. These findings highlight the potential of PMMA and 8% weight percent ZrO_2 nanofillers as effective options for denture based materials.

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INTRODUCTION

Polymethyl methacrylate (PMMA) has been introduced more popular acrylic resin for the fabrication of dentures due to their benefits, which include cheap instrument costs, oral stability, pleasing aesthetics, accurate fitting, and ease of clinical and lab modification [1]. Although this material has been used for the manufacturing of dental restorations through prosthodontics, it was not sufficient to fulfill the optimum functional requirements for dental restorations. This was primarily due to low strain rate and plaque accumulation [2, 3]. According to a study comparing ten different denture base resins, it reported that approximately 70% of the dentures failed during the initial three years of delivery [2]. Upper denture fractures are more prevalent than lower denture fractures, with deboned or split teeth accounting for 33% of denture repairs and midline breaks accounting for 29%, according to studies. The remaining fractures are a variety of different types. Another researcher reported that mandibular partial dentures were widely used and regularly repaired [4]. Therefore, assessing the mechanical and physical characteristics of the foundation material for dentures is essential to determine the impact of different stressing materials [5-7]. Many experiments have been

* Corresponding Author Email: dr.ibrahim@uoa.edu.iq

done to improve the properties of the denture base materials, such as adding an elastomeric stage of evolution [8], metal frames and metal oxides [9, 10], or fibers [11]. Despite this progress, PMMA fracture resistance has yielded only a few encouraging outcomes [12]. Particular focus was placed on strengthening polymers for application in metal-composite dental systems [13]. Through the development of a novel kind of ceramic nanoparticles, the ZnO_2 nanoparticle was selected for improving the biocompatibility of PMMA and to increase the material's superior resistance and hardness in porcelain [14, 15]. The study aims to determine impacts of ZrO_2 nanoparticles on the mechanical properties of hot-cure PMMA.

MATERIALS AND METHODS

The research was investigated to evaluate the ability of ZrO_2 nanofiller powder (in vitro) at different concentrations (2%, 4%, 6%, and 8%) on the transverse and impact stresses at a range of 5 to 15 nm for polymerized heat-cured acrylic resin.

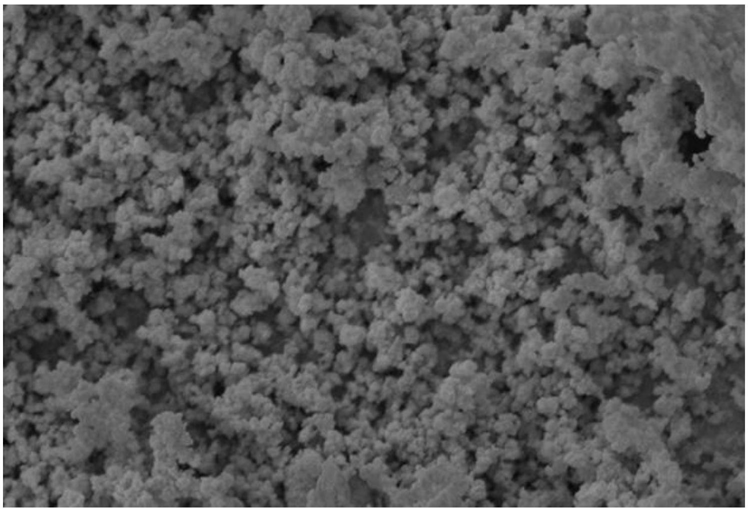

Fig. 1. SEM image of ZrO_2 nanoparticles.

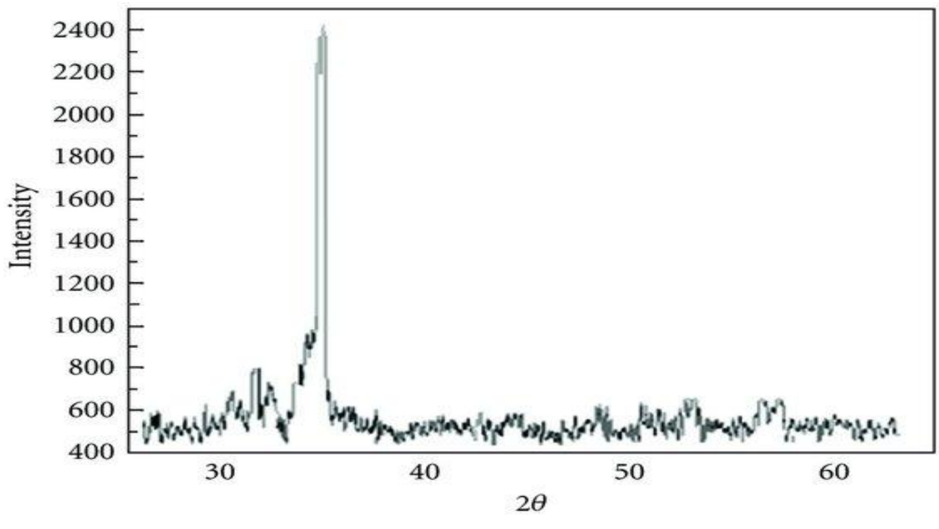

Fig. 2. XRD pattern of ZrO_2 nanoparticles.

Created specimens with the following dimensions: 60 × 7 × 4 mm for impact strength and 65 × 10 × 2.5 mm for transverse strength were employed. As a control, one type of acrylic resin that cures with heat (Classico Dental Products, Sao Paulo, SP, Brazil) and zirconium oxide nanofiller powder (Germany, Batch No. 505/04) was incorporated into heat-cure acrylic resin (PMMA) in various doses (2%, 4%, 6%, and 8%) and processed under optimal conditions with a L/P ratio of 1:3 (via volume). Conventional packing method, short curing cycle (90 min with 74° C) and long curing cycle (30 min with 100° C) was utilized.

RESULTS AND DISCUSSION

Characterization

The SEM micrographs in Fig. 1 demonstrate spherical ZrO_2 nanoparticles along with negligible agglomeration, which possess average size range of 5–15 nm and homogeneous dispersion inside the PMMA matrix.

The XRD pattern in Fig. 2 display distinct diffraction peaks of the monoclinic and tetragonal phases of ZrO_2. The distinctness of the peaks verified elevated crystallinity.

One hundred bar-shaped samples were manufactured for investigation. The samples were separated into transverse stress (Gr. A) and impact stress (Gr. B), with 50 samples in each group. Five subgroups (I, II, III, IV, and V) were created from each of the samples, as seen in Table 1.

Transverse stress test (TS)

According to International Standard Organization 1567, transverse stress testing (TS) is performed for denture base polymers [16, 17]. The following standards are rectangular (65 × 10 × 2.5 mm). A Lloyd universal testing machine (model LRX Plus II, Fareham, England) with a three-point force and a 5 mm/minute crosshead speed was used for the tests. Table 2 and Fig. 3 compare the mean TS in MPa for the examined PMMA grouping. ANOVA

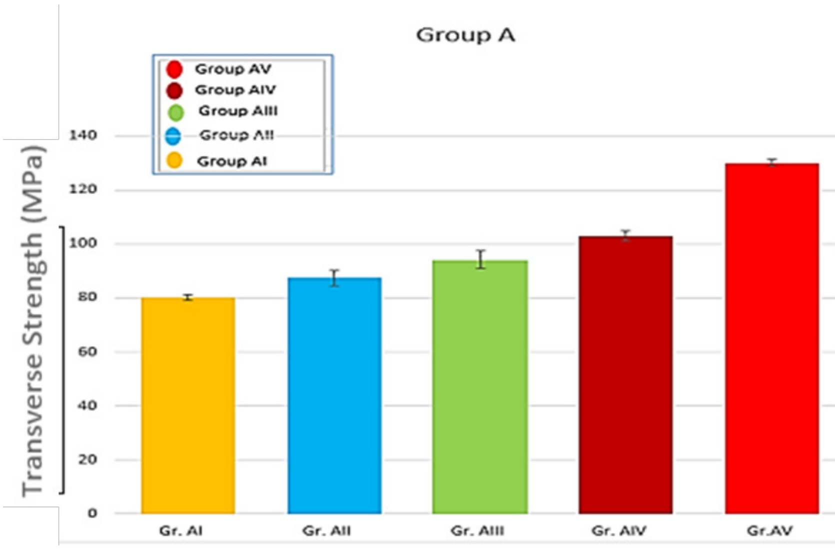

Fig. 3. Bar graph of average transverse stress (MPa) for the PMMA testing groups.

Table 2. A comparison of the mean transverse strength (MPa) of the tested PMMA groups.

Group AI Control group	Group AII (2% ZrO_2)	Group AIII (4% ZrO_2)	Group AIV (6% ZrO_2)	Group AV (8% ZrO_2)	P-value
Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
80.1±1.125	87.4±2.97	94.2±3.3.86	103±2.01	130.1±1.21	0.000*

analysis showed a statistically significant variance between the groups. The PMMA samples with 8% of ZrO_2 nanofiller (Gr. AV) had the highest mean transverse stress, which was followed by samples with 6% (ZrO_2, Gr. AIV), 4% (ZrO_2, Gr. AIII), and 2% (ZrO_2, Gr. AII). The significant variation was among the investigation brands (P≤0.05).

Impact stress test (IS)

Impact strength testing was performed on rectangular-shaped samples (60 × 4 × 7 mm) (IS). Uzun et al. [18] employed a similar sample size and strength test procedure. A 3.5-mm wedge was prepared for the whole sample using a notch cutter. Pressure was applied to the un-notched side of the samples from the Charpy-type impact testing (J/mm^2). Samples that passed the first test without breaking were excluded from the investigation throughout the testing process. The acquired transverse and impact strength values were tabulated, verified for statistical significance, and reported [19]. Tukey's testing and assessment within one variance (ANOVA) were used to examine average significant of the experimental groups, which were statistically significant at P ≤0.05.

The mean transverse stress was substantially lower in a polymethyl methacrylate sample (control group) that did not include other compounds. The groups improved the IS factor. According to the finding in Table 3 and Fig. 4, ZrO_2 reinforcement revealed a substantially high level in IS.

By adding ZrO_2 nanoparticles, researchers hoped to augment the mechanical characteristics

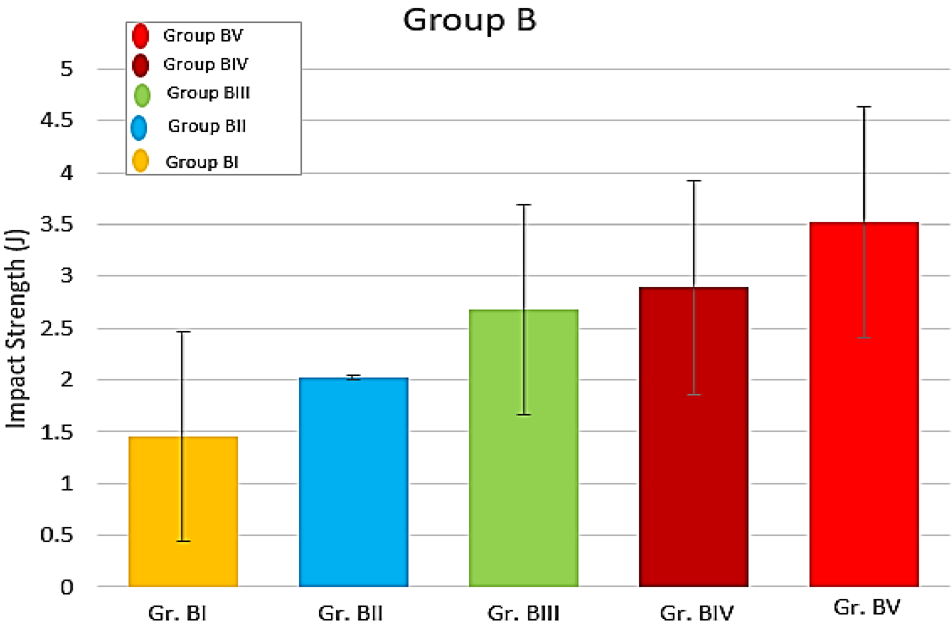

Fig. 4. Bar graph of the average impact strength for the PMMA testing groups.

Table 3. The mean impact strength (J/mm^2) of the tested PMMA groups.

Group B1 Control group	Group B2 (2% ZrO_2)	Group B2 (4% ZrO_2)	Group B2 (6% ZrO_2)	Group B2 (8% ZrO_2)	P-value
Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
1.64±1.01	2.02±0.02	2.68±1.01	2.89±1.03	3.52±1.11	0.000*

of PMMA, particularly the impact and transverse stresses. Three methods exist for improving PMMA's mechanical properties: substituting it with another material, modifying it chemically, or strengthening it with additional materials [20, 21]. Adding ZrO_2 nanofillers enhanced the mechanical characteristics of acrylic resin. Moreover, ZrO_2 has been employed due to its exceptional biocompatibility and a white hue that does not negatively impact aesthetics. Microparticles used in this work improve adaptability with natural polymers, decrease aggregation, and create excellent diffusion [22, 23]. A range of ZrO_2 nanofillers (2–8%) has been chosen as the appropriate overall average since an average of over 7% causes noticeable changes in the acrylic [24]. One type of mechanical stress test is mastication. While mastication attempts to deliver this kind of strength to the denture, TS testing proved that denatured base materials help evaluate them [25]. The TS combines compression shear and tensile stresses that can affect a material's stiffness and ability to withstand fracture [26]. Dentures made of acrylic resin broke when their thickness was reduced, and research is still ongoing to create a more impact-resistant foundation material for dentures. The impact of stress is an essential factor since it may, under some circumstances, represent the force required to shatter a denture, like an accidental fall [26]. Recent study discovered that enhancing the average ZrO_2 fillers significantly improved impact and transverse stresses. The previous research showed high mechanical properties may account for the more excellent surface shear stress that results from bent or supramolecular bonding formation covering or shielding the nanofillers from the composite resin. Additionally, enhanced flexural stress, toughness, and resistance to fracture propagation occurred when the nanofillers in the resin reached their maximum moisture content [27, 28]. This investigation's results align with those of earlier studies [29-31], which unequivocally showed that mechanical qualities may be markedly enhanced by ZrO_2 reinforcement of porcelain and restorative dental resins in addition to acrylic resin.

CONCLUSION

This study emphasis that adding ZrO_2 nanofillers to PMMA boosted the heat-polymerized acrylic resin's transverse and impact strengths. The research findings indicate that the optimal outcomes were attained at an 8% weight concentration.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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