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Evaluation of Mechanical and Biological Properties of Heat-Cured Denture Base Fabricated with Recycled PMMA Powder

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Abstract

Background: Heat-cure polymethylmethacrylate (PMMA) is widely used in dentistry as a denture base material and for training students in fabricating acrylic-based dental appliances. These appliances are typically discarded after training, leading to significant acrylic waste.
Aim: To recycle discarded denture base materials to produce recycled PMMA powder for use in denture base fabrication.
Materials and Methods: The recycled PMMA (rPMMA) powder was produced by grinding the used denture base into the desired particle and later incorporated in different concentrations, 20% and 50%, into the commercial PMMA for denture base fabrication. The mechanical and biological properties of the PMMA modified with rPMMA were investigated. The unmodified denture base fabricated with 100% commercial PMMA powder served as a control group.
Results: The incorporation of 50% rPMMA powder into the PMMA denture base showed slightly more flexural strength (125.80 ± 17.53 MPa) compared to the 20% modified and the control groups. No significant change in the hardness was observed among the groups. Less colony-forming units were observed in the 20% rPMMA modified group (186.33) compared to the other groups.
Conclusion: Denture base materials modified with recycled PMMA (rPMMA) exhibited acceptable mechanical properties and a reduced colony-forming unit (CFU) count compared to unmodified materials.
Keywords: *Candida albicans*, Dentures, Flexural strength, Hardness, Polymethyl methacrylate, Recycling.

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1. Introduction

The denture base is the component of a denture that rests on the foundation tissue and supports the artificial teeth. It absorbs and transmits masticatory forces to the oral structures, such as the hard palate and residual alveolar ridge. In partial dentures, effective force transfer ensures stability and comfort, particularly in distal extensions. In full dentures, close adaptation to the oral mucosa enhances retention [1]. Retention is also influenced by saliva, surface tension, and atmospheric pressure. Beyond function, the denture base contributes to aesthetics by mimicking the appearance of the oral mucosa. An ideal denture base material must meet physical, mechanical, chemical, and biological requirements to endure the oral environment [2]. Polymethyl methacrylate (PMMA) has been widely used for fabricating denture prostheses since its introduction in 1937 [3,4].

During dental training, PMMA is often mishandled by students who are first-time users, leading to errors such as excessive material use, delayed packing, and processing defects like porosity. These mistakes result in significant material waste and increased costs. Additionally, dentures are typically fabricated on standard edentulous models and discarded after training without proper waste management. Although PMMA is biocompatible, it is non-biodegradable, and improper disposal can contribute to environmental pollution. Therefore, effective waste management in dental schools is essential.

Efforts to address this issue have drawn attention to recycling strategies. Similar to plastic waste management through recycling or incineration, the potential for reprocessing discarded denture bases is increasingly being explored. In a related study, Ponnapalli et al. used recycled PMMA (rPMMA) as a filler in gypsum products and observed an increase in compressive strength and setting times, although with reduced surface reproducibility [5]. This demonstrates the feasibility of reusing PMMA waste in dental materials. Although research on recycled PMMA remains limited, recent studies reflect a growing interest in the field, suggesting promising avenues for sustainable waste management in dentistry [6,7]. Therefore, this study aims to recycle denture base materials to produce reusable PMMA powder and to evaluate the effect of its incorporation, at varying concentrations, on the mechanical and biological properties of PMMA-based denture base resins for educational use.

2. Materials and methods

2.1 Preparation and particle size determination of the rPMMA powder

Denture samples fabricated for preclinical practical sessions by students at the Faculty of Dentistry, Universiti Sains Islam Malaysia (USIM), Malaysia were collected for this study. The samples were initially cleaned in an ultrasonic cleaner for 15 minutes, followed by disinfection using 70% alcohol. The denture bases were then mechanically ground using an acrylic bur and further pulverized manually with a pestle and mortar to obtain finer powder particles. The resulting rPMMA powder was stored in an air-sealed bag until further use. Particle size distribution was assessed using sieve analysis, which employed a series of sieves consisting of wire mesh screens with fixed aperture sizes attached to open cylindrical containers.

2.2 Preparation of the denture specimens

The rPMMA powder was blended with commercial PMMA powder at concentrations of 20% and 50% (w/w) to fabricate denture base specimens. These served as the experimental groups and were labelled as R20 and R50, respectively. The control group (labelled as F) comprised unmodified denture base specimens fabricated using 100% commercial heat-cured PMMA powder (Huge Dent, USA). For each group, four specimens (65 × 10 × 3 mm) were prepared for the flexural strength test, and three specimens (10 × 10 × 3 mm) were prepared for the hardness test.

The PMMA powder and liquid were mixed according to the manufacturer's instructions until a dough-like consistency was achieved. The acrylic dough was then packed into a gypsum mold and compressed using a hydraulic bench press (Silfradent, Italy) at 100 bar for 20 minutes. Curing was carried out in a water bath at 93 °C for 3 hours. After curing, the flasks were allowed to bench cool for 30 minutes before the specimens were retrieved. Any surface irregularities were trimmed using a tungsten carbide bur. The specimens were then polished initially with pumice powder on a wet wheel, followed by final polishing with polishing paste on a dry wheel.

2.3 Determination of mechanical properties

Flexural strength was determined using a three-point bending test performed in a universal testing machine (INSTRON 3344, Software: Bluehill 3, Norwood, MA, USA) according to the ISO 1567 standard. Each specimen was placed at a parallel angle on two supports with a span length of 50 mm, and the load was applied until the specimen was fractured. The maximum load exerted on each specimen was recorded and the flexural strength was calculated using formula.

$$FS = 3\,FL/(2bd^2)$$

Where FS is the flexural strength (MPa), F is the force at break (N), L is the span of denture base between the supports, b is the width and d is the thickness.

Vickers hardness test was performed using MTeck HV-1000B (TMTeck Manufacturing Limited, Beijing, China) to determine the surface hardness of each specimen. The 200g force for 15 seconds of dwelling time was applied to produce an indentation on the surface of each specimen using a diamond indentor resulting in the formation of a square indentation (Figure 1). The length of the diagonals was measured microscopically and the hardness value of each specimen was computed. The obtained data were statistically analyzed and compared using a one-way ANOVA test using GraphPad Prism 10.

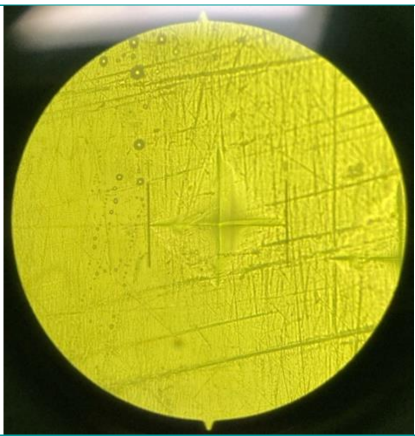

Figure 1. Square-shaped indentation on an acrylic specimen following Vickers hardness testing.

Figure 2. Recycled PMMA powder (right) obtained after the grinding process, compared to commercial PMMA powder (left).

Figure 3. Colony-forming units (CFUs) of *Candida albicans* grown on Sabouraud Dextrose Agar (SDA) after 24-hour incubation.

2.4 Determination of candida adherence properties

Candida adherence was evaluated using nine acrylic denture base specimens (10 × 1 mm), with three samples from each group (F, R20, R50). All specimens were disinfected with alcohol, taking care to avoid altering the surface roughness. Following disinfection, 1.5 mL of *Candida albicans* suspension was added to each well containing the specimens, which were then incubated for 24 hours. After incubation, the discs were washed three times with phosphate-buffered saline (PBS) to remove non-adherent cells, and subsequently transferred to tubes containing 2 mL of PBS. The tubes were sonicated in a water bath at 37 °C for 3 minutes to dislodge adherent C. *albicans* cells from the specimen surfaces. A serial dilution was then performed by transferring 1 mL of the PBS containing dislodged cells into a new tube with 1 mL of PBS; this step was repeated twice to obtain further dilutions. The final dilution was plated on Sabouraud Dextrose Agar (SDA) and incubated for 24 hours. Colony-forming units (CFUs) were then counted using a colony counter.

3. Results

The recycled PMMA powder exhibited a particle size distribution ranging from 0.2 to 0.5 mm (Figure 2).

3.1 Mechanical properties rPMMA denture base material

Table 1 presents the mean and standard deviation of flexural strength and Vickers hardness of the control (F) denture base modified with 20% (R20) and 50% (R50) rPMMA powder. The incorporation of the 20% and 50% rPMMA powder into the denture base did not show any significant difference and had almost comparable flexural strength among the different groups. The denture base material modified with 50% rPMMA showed slightly more flexural strength (125.79 ± 17.53 MPa) and the least was observed with the 20% rPMMA group (120.60 ± 21.15 MPa). However, one-way ANOVA analysis displayed no significant difference (p=0.9029) in the flexural strength among the different groups (Table 1).

The Vickers hardness values among the groups were comparable (Control: 19.00 ± 0.95 VHN; R20: 20.40 ± 0.82 VHN; R50: 20.43 ± 0.42 VHN). Since harder materials exhibit smaller indentation areas, the results suggest similar surface resistance across groups. One-way ANOVA analysis demonstrated no significant difference (p=0.1013) among the different groups (Table 1).

Table 1. Mean and standard deviation of flexural strength and Vickers hardness of denture base resins incorporating rPMMA powder at varying concentrations.

Groups	Flexural strength (MPa)		Surface hardness (VHN)	
	Mean ± SD[#]	p-value	Mean ± SD[#]	p-value
F	121.55 ± 10.66	0.9029	19.00 ± 0.95	0.1013
R20	120.60 ± 21.15		20.40 ± 0.82	
R50	125.79 ± 17.53		20.43 ± 0.42	

[#]Standard deviation.

3.2 Evaluation of *Candida* adherence

Colony-forming unit (CFU) counts were used to assess *Candida* adherence on denture surfaces after 24 hours of incubation in C. *albicans* suspension (Figure 3). The different groups exhibited variability in CFU formation. The control group showed the highest CFU count (391 ± 118.72), followed by the R50 group (355.33 ± 145.66). The R20 group demonstrated the lowest CFU formation (186.33 ± 84.011) compared to the other groups (Figure 4).

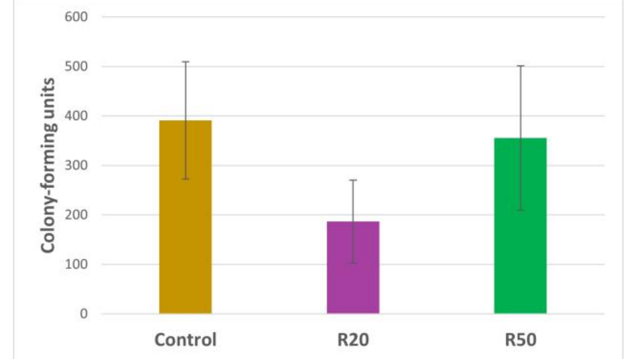

Figure 4. *Candida* adherence to different denture base materials made from rPMMA powder, as assessed by colony-forming units (CFUs), on Sabouraud Dextrose Agar (SDA).

4. Discussion

Heat-cure acrylic denture base resin is widely used for denture bases due to its favorable mechanical and biological properties [4,8]. In the present study, recycled PMMA (rPMMA) at concentrations of 20% and 50% was incorporated into heat-cure denture base resins to evaluate its impact on the mechanical properties and *Candida* adherence on the surface.

In the current study, the differences in flexural strength and Vickers hardness between denture bases incorporated with 20% and 50% recycled PMMA powder were found to be insignificant. This may be attributed to the similar chemical composition of the two powders, making the addition of recycled PMMA powder to the unmodified PMMA powder compatible. As a result, polymerization occurred without the formation of porosity.

Polymethyl methacrylate (PMMA), a widely used denture base material, is classified as a thermoset polymer. Its fabrication involves the combination of PMMA powder with a liquid monomer, methyl methacrylate (MMA), an initiator and a cross-linking agent to facilitate polymerization [8]. Numerous studies have investigated the reinforcement of denture base resins using various fibres and fillers to enhance their mechanical properties [9-13]. In the present investigation, a different approach to material modification was employed by incorporating recycled PMMA (rPMMA) powder, previously polymerized PMMA that had been ground and refined into fine particles, into the conventional PMMA powder. The goal was to achieve particle homogeneity that would allow the recycled polymer to integrate compatibly with the polymerization process of the fresh PMMA and monomer mixture. This technique offers a sustainable alternative for material reuse without significantly compromising the mechanical properties of the final denture base, as demonstrated by the results of flexural strength and hardness tests of this study.

Differences in surface hardness of various denture base materials are often affected by the amount of residual monomer after the curing process [14]. Research reported that the increased addition of rPMMA in the denture base resulted in a decrease in residual monomer released [15]. In the present study, the incorporation of the different concentrations of rPMMA powder demonstrated comparable Vickers hardness with the control group. These findings were in agreement with previous research by Al-Jmmal et al. (2024) [7]. This could be attributed to the higher degree of polymerization with the incorporation of rPMMA powder.

Meanwhile, the result of the *Candida* adherence test showed inconsistency, however, significant differences between 20% and 50% rPMMA along with unmodified denture base material were observed. *Candida albicans* (C. *albicans*) and other *Candida* species are present in the oral cavity in up to 75% of the population [16]. A *Candida* infection occurs when C. *albicans* adhere and multiply on the acrylic base dentures, potentially causing painful inflammation in the oral mucosa near the contaminated dentures [17,18]. The inconsistent reading and significant differences may be due to a factor such as the variable surface roughness. Surface roughness can directly affect the adherence of C. *albicans* cells onto denture surfaces. Thus, making sure the uniformity of surface roughness is important to ensure data consistency and eliminate experimental error. Another factor that may also contribute to the inconsistent finding of C. *albicans* adherence was the irregular particle size of the rPMMA powder itself. This may introduce a rough denture surface and hence requires thorough polishing before any test of microbial colonization can be carried out

[19]. Denture base with smoother surface is less retaining towards stains, improves aesthetics, less C. *albicans* adhesion as well as other microbial colonization. The present study demonstrated that the 20% rPMMA incorporation exhibited less *Candida* adherence and it can be attributed that the denture base material with 20% rPMMA powder could have had less surface roughness compared to the other groups. However, the present study did not evaluate the surface roughness of the different denture base resins used. Therefore, further investigation is required to validate and confirm the findings.

The present study found that incorporating recycled PMMA (rPMMA) powder did not significantly affect the mechanical properties of the denture base resin. However, increased *Candida* adherence was observed with higher concentrations of rPMMA. It is important to note that this in vitro study does not fully replicate the complex conditions of the oral environment, where materials may behave differently. Additionally, the sample size in this study was relatively limited. Future research should focus on evaluating the performance of these modified materials under in vivo conditions using larger sample sizes to better standardize their mechanical and biological properties. Further investigations could also explore the material's response to a broader range of oral microorganisms.

5. Conclusion

The mechanical properties of specimens fabricated with 20% and 50% recycled PMMA (rPMMA) showed no significant difference compared to those made from 100% commercial PMMA resin. This suggests that the incorporation of rPMMA powder does not compromise the quality of denture bases, at least for applications such as edentulous models and educational purposes. Such an approach offers a sustainable method for managing material waste while also providing a cost-effective alternative for dental training centres.

Conflicts of interest: Authors declared no conflicts of interest.

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