

Effect of betung bamboo fiber nanocellulose addition to heat-polymerized acrylic resin denture base material on impact strength: an experimental study

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ABSTRACT

Introduction: Resin Heat-polymerized acrylic resin is commonly used to fabricate denture bases; however, it has several disadvantages, including low impact strength, which makes it more susceptible to fracture. This limitation may be addressed by adding betung bamboo fiber nanocellulose as a reinforcing material. Nanocellulose has smaller particle sizes and greater homogeneity. This study aimed to analyze the effect of adding betung bamboo fiber nanocellulose at concentrations of 0.5%, 0.75%, and 1% to heat-polymerized acrylic resin denture bases on impact strength. **Methods:** This was an experimental laboratory study. Heat-polymerized acrylic resin denture base specimens without added betung bamboo fiber nanocellulose served as the control group (Group A). Specimens with 0.5% (Group B), 0.75% (Group C), and 1% (Group D) betung bamboo fiber nanocellulose served as the treatment groups. A total of 32 specimens measuring 65 × 10 × 2.5 mm were prepared using a brass metal mold. The specimens were tested using the Charpy impact test to determine impact strength. **Results:** The mean ± standard deviation impact strength values were 9.99 ± 1.63 × 10⁻³ J/mm² for Group A, 12.05 ± 0.84 × 10⁻³ J/mm² for Group B, 13.8 ± 0.75 × 10⁻³ J/mm² for Group C, and 14.58 ± 0.88 × 10⁻³ J/mm² for Group D. One-way ANOVA showed a significant difference ($p=0.0001$; $p<0.05$), and the LSD test also showed a significant difference ($p=0.0001$; $p<0.05$). **Conclusion:** The addition of betung bamboo fiber nanocellulose to heat-polymerized acrylic resin denture base material had a significant effect on impact strength.

Keywords

Heat-polymerized acrylic resin, nanocellulose, betung bamboo fiber, impact strength

Perbedaan efek penambahan nanoselulosa serat bambu betung pada bahan basis gigi tiruan resin akrilik polimerisasi panas terhadap kekuatan impak: studi eksperimental

ABSTRAK

Pendahuluan: Resin akrilik polimerisasi panas sering digunakan untuk membuat basis gigi tiruan, namun RAPP memiliki kekurangan diantaranya kekuatan impak yang rendah sehingga lebih mudah terjadi fraktur. Hal ini dapat diatasi dengan menambahkan bahan penguat nanoselulosa serat bambu betung. Nanoselulosa memiliki ukuran partikel yang lebih kecil serta memiliki homogenitas yang lebih baik. Penelitian ini bertujuan untuk menganalisis perbedaan efek penambahan nanoselulosa serat bambu betung dengan konsentrasi 0,5%, 0,75%, dan 1% pada basis gigi tiruan RAPP terhadap kekuatan impak. **Metode:** Penelitian ini adalah penelitian eksperimental laboratoris. Penelitian ini dilakukan pada sampel basis gigi tiruan resin akrilik polimerisasi panas dengan kelompok tanpa penambahan nanoselulosa serat bambu betung sebagai kelompok kontrol (kelompok A) dan dengan penambahan nanoselulosa serat bambu betung 0,5% (kelompok B), 0,75% (kelompok C) dan 1% (kelompok D) sebagai kelompok perlakuan. Sampel dibuat dengan ukuran 65×10×2,5 mm sebanyak 32 sampel, dan berbentuk logam kuningan. Sampel diuji dengan Uji impak charpy untuk menganalisis nilai kekuatan impak. **Hasil:** Nilai rata-rata dan standar deviasi kekuatan impak pada kelompok A sebesar 9,99 ± 1,63 × 10⁻³ J/mm², kelompok B sebesar 12,05 ± 0,84 × 10⁻³ J/mm², kelompok C sebesar 13,8 ± 0,75 × 10⁻³ J/mm² dan kelompok D sebesar 14,58 ± 0,88 × 10⁻³ J/mm². Hasil uji ANOVA satu arah diperoleh nilai signifikansi $p=0,0001$ ($p<0,05$) dan uji LSD yang signifikan dengan nilai $p = 0,0001$ ($p<0,05$). **Simpulan:** Terdapat perbedaan efek penambahan nanoselulosa serat bambu betung pada bahan basis gigi tiruan resin akrilik polimerisasi panas terhadap kekuatan impak.

Kata kunci

Resin akrilik polimerisasi panas, nanoselulosa, serat bambu betung, kekuatan impak

INTRODUCTION

Dentures are devices used to replace some or all missing natural teeth to improve mastication, taste perception, esthetics, and tissue health, as well as to prevent further damage to oral tissue structures caused by tooth loss.¹ Based on their mode of retention, dentures are classified into two types: fixed dentures and removable dentures.² A denture base is the component of a removable denture that is supported through close adaptation to the underlying oral tissues. Heat-polymerized acrylic resin (HPAR) is currently the most widely used denture base material because it has several advantages, including being non-toxic, gingiva-like in color, non-irritating to tissues, physically and esthetically satisfactory, insoluble in saliva, easy to manipulate and fabricate, repairable, dimensionally stable, and relatively inexpensive.^{3,4}

However, this material has disadvantages, including low impact strength, making it more susceptible to fracture. Most HPAR denture base fractures occur along the midline of the denture and may be associated with conditions such as a high palate, a large torus, repeated sudden impacts on the denture in patients with Parkinson's disease or dementia, and material fatigue caused by repeated masticatory forces in the oral cavity.^{5,6} Adding reinforcing materials to denture bases is one approach to improving the mechanical properties of HPAR denture base materials, including impact strength. The addition of fibers to acrylic resin may improve its mechanical properties; one example is betung bamboo fiber. Betung bamboo fiber has a high cellulose content, approximately 66.39%–74.76%, which provides strength and stiffness.⁷

Bamboo grows well in tropical and subtropical regions; therefore, Indonesia, as a tropical country with a favorable climate, is an ideal location for bamboo cultivation. Bamboo has various applications, including house and bridge construction, the manufacture of household utensils such as spoons and chopsticks, and use as a filler or composite material in heat-polymerized acrylic resin.⁸ Cellulose is currently used at the nanoscale, in the form of nanocellulose, because nanocellulose has unique properties that combine important characteristics of cellulose, such as hydrophilicity and extensive chemical modifiability, with the specific properties of nanoscale materials.^{9,10}

The primary reason for increasing interest in nanomaterials is their ability to produce highly uniform materials with enhanced mechanical properties through the reduction in cellulose fiber size. Nanocellulose can also increase particle surface area and fill empty spaces, thereby improving the strength of the resulting composite. This is mainly related to its large surface area, which makes it a lightweight material with high strength and stiffness.

A study by Aupaphong et al. examined the addition of bamboo fiber cellulose nanocrystals to heat-polymerized acrylic resin denture base material and evaluated transverse strength. The study used bamboo fiber nanocrystals at concentrations of 0.25%, 0.5%, 1%, and 2%. The results showed a significant increase in transverse strength in the 0.5% group, whereas transverse strength decreased in the 1% and 2% groups compared with the control group.¹¹ Meanwhile, Elonianty C. investigated the addition of *Bambusa arundinacea* (Retz.) Willd. fibers with lengths of 2 mm, 6 mm, and 12 mm and weights of 3 wt%, 6 wt%, and 9 wt% to acrylic resin denture base material to determine its effect on impact strength.

The results demonstrated a significant difference in the impact strength of heat-cured acrylic resin after the addition of *Bambusa arundinacea* (Retz.) Willd. fibers. The addition of these fibers increased the impact strength of heat-cured acrylic resin as fiber length and weight increased.¹² Kongkaew et al. found that increasing fiber concentration increased cellulose concentration; however, the impact strength decreased as fiber concentration increased.¹³ No studies have been identified that evaluate the effect of adding betung bamboo fiber nanocellulose to HPAR denture base material on impact strength. This may occur because the fiber–matrix bond is weak and the stress-transferring matrix lacks

sufficient strength to support the fibers. The quality of a fiber-reinforcing material depends on fiber length, fiber diameter, fiber quality, flexibility, and smoothness.

Based on the study by Aupaphong et al., which evaluated bamboo fiber cellulose nanocrystals at concentrations of 0.25%, 0.5%, 1%, and 2% in heat-polymerized acrylic resin denture base material, a significant increase in transverse strength was observed in the 0.5% group, whereas transverse strength decreased in the 1% and 2% groups compared with the control group.^{14,15} Therefore, it is necessary to investigate whether adding betung bamboo fiber nanocellulose at concentrations of 0.5%, 0.75%, and 1% to HPAR denture base material affects impact strength. This study aimed to analyze the effect of adding betung bamboo fiber nanocellulose at concentrations of 0.5%, 0.75%, and 1% to HPAR denture base material on impact strength.

METHODS

This was an experimental laboratory study using a posttest-only control group design. The study was conducted at the Integrated Laboratory, Faculty of Dentistry, Universitas Sumatera Utara, and the Research Room of the Department of Prosthodontics, Faculty of Dentistry, Universitas Sumatera Utara, for acrylic resin specimen preparation; the Phytochemistry Laboratory, Faculty of Pharmacy, Universitas Sumatera Utara, for extraction of betung bamboo fiber cellulose; and the Mechanical Engineering Laboratory, Universitas Harapan Medan, for impact strength testing.

The study used 32 rectangular heat-polymerized acrylic resin denture base specimens measuring 65×10×2.5 mm, in accordance with International Organization for Standardization (ISO) No. 1567. The specimens were divided into four groups of eight specimens each, based on the Federer method: a control group (Group A); a group with 0.5% betung bamboo fiber nanocellulose (Group B); a group with 0.75% betung bamboo fiber nanocellulose (Group C); and a group with 1% betung bamboo fiber nanocellulose (Group D).

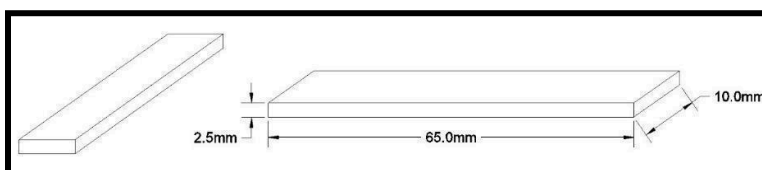


Figure 1. Design of the brass master model

The study began with the preparation of betung bamboo fiber. For cellulose extraction, betung bamboo was cut into approximately 1 m sections, split in half, peeled, and planed. The bamboo pieces were ground using a blender to obtain fibers. The bamboo fibers were then washed with distilled water and dried in a drying cabinet for 24–48 h. The dried fibers were sieved through a 60-mesh sieve. A total of 250 g of bamboo fibers was prepared and dissolved in 2,500 mL of 2.5% NaOH, then heated for 2 h at 80°C using a thermostatic hot plate. This delignification stage was performed to remove lignin. The sample was subsequently rinsed with distilled water and filtered. Next, 10 g of the alkali-treated sample was bleached with 40 mL of 24% H₂O₂ and heated at 70°C for 40 min.

The sample was rinsed with distilled water and filtered, then dried in a drying cabinet for 24 h. The dried sample was blended and sieved through a 60-mesh sieve. Nanocellulose was produced using a mechanical method with a ball mill. Betung bamboo fiber cellulose was processed in a ball mill for 2 h at a rotational speed of 1,200 rpm. Particle size analysis (PSA) was then performed, producing betung bamboo fiber cellulose nanofibrils with a particle size of 370 nm.

The mold was prepared by mixing Type III gypsum with water at a ratio of 300 g to 90 mL to fill the lower half of the denture flask. The gypsum mixture was mixed thoroughly in a rubber bowl and poured into the lower flask while vibrating. Three master models were embedded in the gypsum surface and allowed to set for 45 min.

Cold mould seal was applied to the set gypsum surface. The upper half of the denture flask was then filled with the same gypsum mixture, and the lower and upper halves of the flask were assembled. The flask was pressed and allowed to set for 45 min. After the gypsum had set, the flask was opened and the master models were removed. After drying, cold mould seal was applied to the gypsum surface and allowed to dry for 20 min.

To prepare the heat-polymerized acrylic resin denture base specimens, polymer and monomer were mixed in an acrylic mixing jar at a ratio of 15 g to 7.5 mL. The previously prepared betung bamboo fiber nanocellulose reinforcement was added to the polymer–monomer mixture according to the designated concentration. After the mixture was thoroughly blended and reached the dough stage, it was placed into the mold.

The heat-polymerized acrylic resin dough was covered with clear plastic, and the mold was closed. The mold was pressed using a hydraulic press at 1,000 psi, then opened, and excess acrylic resin was removed using a Le Cron instrument. The denture flask was closed and pressed again at 2,200 psi. The flask was reclosed and secured using the bolts on the flask, then left for 15 min. The flask was subsequently placed in a water bath at 70°C for 90 min. The temperature was then increased to 100°C and maintained for 30 min.

The flask was allowed to cool to room temperature for 30 min while being immersed in running water for 15 min. The specimens, measuring 65 × 10 × 2.5 mm, were removed from the mold, and sharp edges were trimmed using a Fraser bur. The specimens were finished with 400-, 800-, and 1,200-grit sandpaper using a rotary grinder. They were polished using a green polishing bur, a wool polishing bur, and pumice powder. The specimens were tested using a Charpy impact tester to measure impact strength.

Data analysis included descriptive analysis to calculate the mean and standard deviation of impact strength. One-way ANOVA was used to evaluate the effect of adding betung bamboo fiber nanocellulose at concentrations of 0.5%, 0.75%, and 1% on the impact strength of HPAR denture base material. The least significant difference (LSD) test was used to compare the differences in the effects of adding betung bamboo fiber nanocellulose at concentrations of 0.5%, 0.75%, and 1% on the impact strength of HPAR denture base material.

RESULTS

Descriptive analysis showed that the mean ± standard deviation impact strength values were $9.99 \pm 1.63 \times 10^{-3}$ J/mm² for Group A, $12.05 \pm 0.84 \times 10^{-3}$ J/mm² for Group B, $13.8 \pm 0.75 \times 10^{-3}$ J/mm² for Group C, and $14.58 \pm 0.88 \times 10^{-3}$ J/mm² for Group D (Table 1).

Table 1. Impact strength of HPAR denture base material with and without the addition of 0.5%, 0.75%, and 1% betung bamboo fiber nanocellulose

No Sample	Control (A)	0.5 % (B)	0.75 % (C)	1% (D)
1	10.8	12.3	12.4*	13.2*
2	10.9	12.9	13.3	14.8
3	12.3**	13.1**	13.9	15.5
4	10.3	11.9	13.6	15.8**
5	11.1	11.3	13.8	15.1
6	8.6	10.5*	14.1	13.8
7	7.9*	12.0	14.3	14.1
8	8.0	12.4	15.0**	14.3
$\bar{X} \pm SD$	9.99 ± 1.63	12.05 ± 0.84	13.8 ± 0.75	14.58 ± 0.88

Note: *Lowest value, **Highest value

One-way ANOVA showed a $p=0.0001$ ($p<0.05$), indicating that the addition of 0.5%, 0.75%, and 1% betung bamboo fiber nanocellulose to heat-polymerized acrylic resin denture base material affected impact strength (Table 2).

Table 2. Effect of betung bamboo fiber nanocellulose addition to heat-polymerized acrylic resin denture base material on impact strength

Group	n	Impact strength(J/mm ²)	
		$\bar{X} \pm SD$	P
A (Control)	8	9.99 $\pm$ 1.63	0.0001*
B (0.5 %)	8	12.05 $\pm$ 0.84	
C (0.75 %)	8	13.8 $\pm$ 0.75	
D (1%)	8	14.58 $\pm$ 0.88	

Note: *Significant ($p < 0.05$)

The least significant difference (LSD) test was used to analyze which treatment pairs differed significantly between groups. The LSD test showed significant differences in impact strength between Group A and Group B ($p=0.001$; $p<0.05$), Group A and Group C ($p=0.0001$; $p<0.05$), Group A and Group D ($p=0.0001$; $p<0.05$), and Group B and Group C ($p=0.003$; $p<0.05$) (Table 3).

Table 3. Differences in the effect of betung bamboo fiber nanocellulose addition to heat-polymerized acrylic resin denture base material on impact strength

Group	A	B	C	D
A (Control)	-	0.001*	0.0001*	0.0001*
B (0.5 %)	0.001*	-	0.003*	0.0001*
C (0.75 %)	0.0001*	0.003*	-	0.164
D (1%)	0.0001*	0.0001*	0.164	-

Note: *Signifikan ($p<0.05$)

DISCUSSION

Impact strength values varied among specimens in Groups A, B, C, and D (Table 1). This finding is consistent with a study by Jarboo et al. (2020), which stated that changes in impact strength may occur during the pressing process due to uneven filler distribution.¹⁷ This variation may be caused by factors affecting the polymerization process of heat-polymerized acrylic resin (HPAR) denture base material. For example, non-simultaneous mixing of the monomer and polymer may result in variable specimen quality. In addition, variations in mixing strength and speed among specimens may trap air within the HPAR matrix, causing internal porosity that may affect impact strength. To produce a better mixture without air voids or internal porosity, mechanical mixing using a vacuum resin mixer may be performed.

The use of a vacuum resin mixer can provide uniform mixing strength and speed for each specimen, resulting in better mixing of nanocellulose with HPAR.¹⁶ Another factor that may cause variation in impact strength is the distribution of the reinforcing material during pressing. Some nanocellulose mixed with HPAR may spread laterally and extrude beyond the mold during pressing, reducing the nanocellulose concentration in each specimen. This finding is consistent with the study by Jarboo et al., which stated that changes in impact strength may occur during pressing due to uneven filler distribution.¹⁷

One-way ANOVA showed a significant result ($p = 0.0001$; $p < 0.05$). This indicates that the addition of 0.5%, 0.75%, and 1% betung bamboo fiber nanocellulose to heat-polymerized acrylic resin significantly increased impact strength. This finding is supported by a study by Hasran et al. on the effect of adding rice husk nanocellulose at concentrations of 1%, 2%, 3%, 4%, and 5% on the impact strength of HPAR denture base

material. The results showed an increase in HPAR impact strength, with the greatest significant increase occurring in the group with 5% rice husk nanocellulose.²⁰

This may have occurred because the most appropriate concentration of betung bamboo fiber had been reached compared with the other treatment groups. The primary function of fibers in acrylic resin is to transfer stress received by the acrylic resin to the fibers. Fibers also help distribute forces across the acrylic resin plate. Fibers added to acrylic resin should have greater strength than the acrylic resin because they are expected to withstand forces up to their maximum limit.

The cellulose in betung bamboo fiber may increase adhesion between the fibers and the acrylic resin polymer matrix, thereby increasing impact strength. Cellulose can increase fiber-matrix adhesion because the cellulose in betung bamboo fibers can be activated through an alkalization process using NaOH solution. This alkalization process breaks hydrogen bonds in cellulose and produces Na⁺ groups in the cellulose. The Na⁺ groups in cellulose bind to OH⁻ groups in the acrylic resin polymer matrix, thereby forming strong hydrogen bonds between the fibers and matrix.

Strong adhesion may also prevent separation of the nanocellulose from the matrix when subjected to loading or pressure. If the available acrylic resin monomer is fully used in the chemical bonding reaction between the acrylic resin polymer and the total concentration of nanocellulose, complete chemical bonding will occur. Complete chemical bonding results in uniform load distribution throughout the acrylic resin base. Strong interactions between nanocellulose and the polymer form a strong network and improve the material's mechanical strength.^{18,19,20}

Nanoparticles have a larger surface area than larger particles. Kongkaew et al. found that increasing fiber concentration increased cellulose concentration; however, impact strength decreased as fiber concentration increased.¹³ The large surface area allows nanoparticles to interact more effectively with other materials. Nanoparticles may be stronger and stiffer than larger particles. Thus, the addition of nanocellulose to heat-polymerized acrylic resin may improve mechanical properties, including impact strength.^{21,22}

This finding is consistent with the study by Hasran et al., which evaluated the addition of rice husk nanocellulose at concentrations of 1%, 2%, 3%, 4%, and 5% to HPAR denture base material. The results showed increased impact strength, with the greatest significant increase occurring in the treatment group with 5% rice husk nanocellulose.²⁰

The LSD test showed no significant difference in impact strength between the group with 0.75% betung bamboo fiber nanocellulose (Group C) and the group with 1% betung bamboo fiber nanocellulose (Group D) ($p = 0.164$; $p > 0.05$). Excessively high nanocellulose concentrations may also reduce the impact strength of acrylic resin. According to Khalil, contraction of acrylic resin that disrupts the homogeneous structure of the polymer layer on the nanocellulose surface may weaken the chemical bonds between acrylic resin and nanocellulose. This may reduce the impact strength that can be tolerated by the acrylic resin; therefore, as more nanocellulose is added, impact strength may decrease.²¹

The 1% betung bamboo fiber nanocellulose group showed the highest concentration level among the groups in this study. However, statistically, there was no significant difference between the 1% and 0.75% nanocellulose groups. Increasing nanocellulose concentration may improve resistance to fracture; however, the quantity of nanocellulose added and the optimum fiber content should also be considered.^{23,24,25}

The optimum value is the point at which the nanocellulose volume fraction provides maximal resistance to forces applied to the matrix. Excessively high nanocellulose concentrations may reduce the impact strength of acrylic resin.^{26,27} According to Khalil, contraction of acrylic resin that disrupts the homogeneous structure of the polymer layer on the nanocellulose surface may weaken the chemical bonds between acrylic resin and

nanocellulose. This may reduce the impact strength that can be tolerated by the acrylic resin; therefore, as more nanocellulose is added, impact strength may decrease.²¹

The impact strength of the group with 1% betung bamboo fiber nanocellulose was higher than that of the group without betung bamboo fiber nanocellulose and the groups with 0.5% and 0.75% nanocellulose. A concentration of 1% was the most favorable concentration for addition to heat-polymerized acrylic resin, although it did not differ significantly from the 0.75% nanocellulose group. In clinical terms, an HPAR denture base containing 1% nanocellulose may be more resistant to fracture and better able to withstand sudden impact loads.

The limitations of this study include non-simultaneous mixing of the HPAR denture base monomer and polymer, which may have resulted in variable specimen quality; variations in mixing strength and speed among specimens, which may have trapped air in the HPAR matrix and caused internal porosity that could affect impact strength; and the absence of scanning electron microscopy (SEM) and X-ray diffraction (XRD) to identify microstructural morphology and crystallinity in the test specimens.²⁸⁻³⁰ The investigated HPAR property was limited to impact strength; therefore, further research is needed to examine the effect of betung bamboo fiber nanocellulose on other HPAR properties.

CONCLUSION

The addition of betung bamboo fiber nanocellulose to heat-polymerized acrylic resin denture base material affected impact strength. The highest impact strength was observed in Group D with 1% betung bamboo fiber nanocellulose, followed by Group C with 0.75%, Group B with 0.5%, and Group A without betung bamboo fiber nanocellulose. The findings may assist dentists in considering the addition of nanocellulose to heat-polymerized acrylic resin denture base material, as different nanocellulose concentrations may have different effects on impact strength.

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Informed Consent Statement: Not applicable. This study did not involve human or animal participants.

Data Availability Statement: Research data will be made available with the approval of all researchers through correspondence, in accordance with research ethics.

Conflicts of Interest: The authors declare no conflicts of interest.

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