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Surface Roughness Analysis of Aramid Pulp- Reinforced PMMA for Denture Base Application- An in Vitro Study

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KEYWORDS

PMMA; aramid pulp; denture base; surface roughness; composite materials; dental prosthetics; reinforcement; in vitro study

ABSTRACT:

Introduction: The surface roughness of denture base materials plays a significant role in clinical performance, impacting plaque accumulation, aesthetics, and patient comfort. Polymethyl methacrylate (PMMA) is widely used in prosthodontics for its favorable mechanical properties and biocompatibility. However, its surface characteristics can be further improved through reinforcement. Aramid pulp, known for its high tensile strength and thermal stability, has emerged as a promising reinforcing agent. This in vitro study aimed to assess the effect of incorporating 5% and 10% aramid pulp into PMMA on surface roughness after 30 days of immersion in artificial saliva.

Objectives: To evaluate and compare the surface roughness of PMMA denture base resin reinforced with aramid fibers (5% and 10%) and to assess the effect of aramid fiber incorporation on its surface texture.

Methods: Thirty rectangular heat-cure PMMA specimens were fabricated and divided into three groups (n = 10 each):

- **Group I (Control):** Unmodified PMMA
- **Group II:** PMMA with 5% aramid pulp
- **Group III:** PMMA with 10% aramid pulp

Specimens were immersed in artificial saliva at 37°C for 30 days. Surface roughness (Ra) was measured using a Mitutoyo SJ-210 surface roughness tester. Data were analyzed using one-way ANOVA with significance set at $p < 0.05$.

Results: Group II exhibited the highest mean surface roughness (1.065 µm), while Group III had slightly lower roughness (0.982 µm) with improved consistency. Group I showed the lowest values. ANOVA revealed a statistically significant difference among the groups ($F = 3.683$, $p = 0.039$).

Conclusions: Aramid pulp reinforcement modifies PMMA surface properties. A 10% concentration offers smoother, more consistent surfaces, making it potentially more suitable for long-term prosthetic success by enhancing aesthetics, hygiene, and patient satisfaction.

1. Introduction

Polymers like Polyethylene (PE), Poly methyl methacrylate (PMMA), Polycarbonate (PC), and Polyethylene glycol (PEG) are widely used in dentistry for various applications, including preventive, restorative, and regenerative treatments. These polymers have high molecular weight, consisting of repeating units from their monomers, and are critical in clinical dentistry.[1] PMMA is particularly favored due to its low density, aesthetic appeal, cost-effectiveness, and ease of manipulation, though its physical and mechanical properties are not ideal for long-term durability.[2,3]

Studies aim to enhance PMMA's properties through different methods, such as altering monomer proportions, reducing water storage phases in dentures, and using chemical curing.[4] Surface imperfections in restorative materials, like PMMA dentures, can impact durability, promoting biofilm formation and microbial growth. Surface roughness plays a key role in this, and polishing methods, both mechanical and chemical, can reduce roughness to improve plaque resistance and microbial adhesion.[5]

Mechanical polishing, using techniques like pumice and lathe polishing, helps achieve a smoother surface, while chemical polishing, such as immersing the denture in heated monomer, polishes both surfaces effectively.[6] Despite recommendations for patients to use abrasive paste and cleaning brushes for denture hygiene, effectiveness can be limited due to patient noncompliance. Water absorption is another concern, as it can weaken the denture's mechanical properties and cause discoloration.[7]

To enhance the aesthetic and functional properties, surface sealants are used to fill microstructural imperfections, improving color stability, resistance to stains, and wear. Mechanical polishing has been shown to achieve smoother surfaces than chemical polishing, though it is more time-consuming.[6,8]

An upcoming study will explore reinforcing PMMA with aramid fiber, known for its strength, low density, and durability. Aramid fiber, particularly in pulp form, could improve the surface properties of PMMA in dental applications, leveraging its unique characteristics to enhance the material's overall performance.[9]

2. Objectives

The primary objective of this in vitro study is to evaluate the effect of incorporating aramid pulp fibers at different concentrations (5% and 10% by weight) into polymethyl methacrylate (PMMA) denture base resin on its surface roughness. Since surface texture plays a pivotal role in determining denture longevity, comfort, and hygiene, this study focuses on whether aramid reinforcement alters the surface characteristics of PMMA after immersion in artificial saliva for a clinically relevant duration of 30 days.

A secondary objective is to compare the reinforced groups with conventional unmodified PMMA, thereby determining the concentration of aramid pulp that provides smoother and more consistent surfaces. By doing so, the study seeks to establish whether reinforcement with aramid fibers can enhance the clinical applicability of PMMA denture bases by improving biocompatibility, reducing plaque accumulation, and contributing to greater patient satisfaction.

3. Methods

Study Setting and Objective

This in vitro experimental study was conducted in the Department of Prosthodontics, Crown and Bridge and Implantology at NIMS Dental College and Hospital. The primary objective was to investigate the influence of aramid pulp fiber reinforcement on the surface roughness of heat-cured polymethyl methacrylate (PMMA), a commonly used denture base resin. The study specifically aimed to compare surface characteristics of unreinforced PMMA with PMMA reinforced with 5% and 10% aramid pulp by weight. The rationale for selecting surface roughness as the evaluation parameter stems from its significant role in denture performance—it affects biofilm accumulation, hygiene maintenance, aesthetics, and patient comfort. A smoother surface typically promotes better oral health and longer prosthesis lifespan, while rougher surfaces increase the risk of microbial colonization and staining.

Materials Used

The materials employed in this study included:

- **Heat-cure PMMA resin** (Coltent–Colto Cure), a standard denture base material known for its ease of manipulation, biocompatibility, and mechanical strength.

- **Aramid pulp fibers**, a synthetic polymer derived from aromatic polyamides, recognized for their excellent mechanical properties, high modulus of elasticity, thermal stability, and resistance to degradation. Aramid pulp [figure 1] was selected in fibrous form to facilitate uniform dispersion within the PMMA matrix.

Both materials were procured from reputable commercial sources, and care was taken to store them in accordance with manufacturer guidelines to preserve material integrity prior to use.

Sample Preparation

A total of **30 rectangular specimens** were fabricated using a **stainless-steel split mold**, each measuring **65 mm × 10 mm × 3 mm**, [Figure 2] as specified by the **American Dental Association (ADA) Specification No. 12**. The choice of specimen size was based on standard testing dimensions for surface evaluation to ensure accurate and reproducible results.

The specimens were randomly divided into three groups (n = 10 per group):

- **Group I (Control):** PMMA without reinforcement (pure base resin)
- **Group II:** PMMA reinforced with **5% aramid pulp by weight**
- **Group III:** PMMA reinforced with **10% aramid pulp by weight**

For the control group, PMMA polymer powder and monomer liquid were mixed in the manufacturer's recommended 3:1 ratio by volume. The mixture was allowed to reach the dough stage through bench curing, and then packed into the mold and polymerized using a conventional water-bath curing technique at 74°C for 2 hours followed by 100°C for 1 hour to ensure complete polymerization.

In the experimental groups (Groups II and III), aramid pulp was carefully weighed using a digital precision balance to match 5% and 10% by weight of the PMMA powder, respectively[Figure 3]. The pulp was slowly added to the polymer and blended manually to achieve uniform dispersion. This reinforced powder was then mixed with monomer and processed identically to the control group. The same curing cycle was used for all groups to eliminate processing bias. Meticulous care was taken during mixing to prevent fiber clumping or the inclusion of air bubbles that could compromise mechanical integrity or affect surface roughness.

Finishing and Polishing

After polymerization and retrieval from the mold, all specimens underwent **standardized finishing and polishing** procedures to ensure a clinically relevant and uniform surface across all groups. Initially, gross irregularities and flash were removed using **tungsten carbide burs**. The surfaces were then sequentially smoothed using **silicon carbide abrasive papers** of increasing grit sizes (180, 220, and 400 grit) under running water to prevent heat generation and distortion.

The final polishing step involved the use of **pumice slurry** and **muslin polishing wheels** mounted on a lathe at controlled speed. **Soft bristle brushes** were used during pumice polishing to replicate clinical intraoral polishing techniques. Polishing was done consistently across all specimens to minimize operator variability and ensure that surface roughness was influenced only by the reinforcement and not by finishing quality.

Aging in Artificial Saliva

To simulate oral environmental conditions, all polished specimens were immersed in **artificial saliva** and stored at **room temperature (approximately 25°C)** for a period of **30 days**. The artificial saliva used in this study was prepared following a standard formula containing electrolytes such as sodium, calcium, and phosphate ions, mimicking natural saliva's composition. This aging protocol aimed to replicate the exposure of denture base materials to moisture, enzymes, and pH fluctuations encountered in the oral cavity, potentially affecting surface topography over time. Solutions were replaced every 3 days to prevent microbial contamination and degradation of artificial components.

Surface Roughness Measurement

Following the 30-day immersion period, the surface roughness of each specimen was evaluated using a **Mitutoyo Surface Roughness Tester (SJ-210 model)**. This portable stylus-based instrument provides precise Ra values (average surface roughness) in micrometers

(µm) and is widely accepted for dental material surface evaluation. Prior to measurement, the device was calibrated using a standard reference specimen. Each sample was placed on a vibration-free platform, and the stylus was run longitudinally across the center of the specimen at three different locations. The mean of these three readings was calculated for each specimen to ensure accuracy and reduce variability.

Morphological Analysis

In addition to quantitative surface roughness analysis, **Scanning Electron Microscopy (SEM)** was utilized to qualitatively assess the internal morphology and surface structure of the PMMA-aramid composites. SEM analysis was carried out at multiple magnifications (500x to 3000x) to evaluate the **dispersion**, **orientation**, and **fiber-matrix adhesion** of the aramid pulp within the PMMA resin. Representative samples from each group were sputter-coated with gold-palladium to enhance conductivity before being scanned. This morphological assessment provided insight into how fiber reinforcement influenced not only surface characteristics but also the microstructural integrity of the composite, which may affect long-term performance.

Figure 1: Aramid Pulp

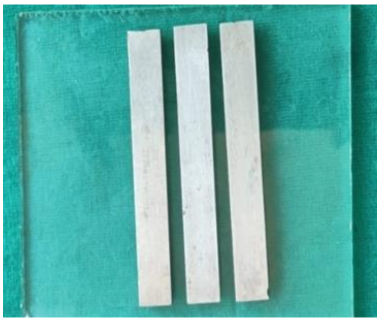
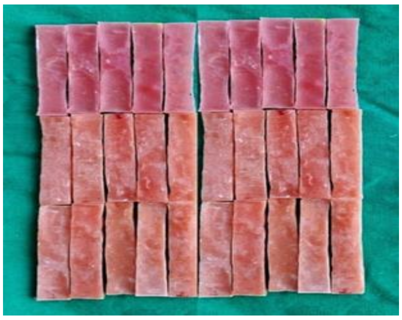


Figure 2: Master Die



4. Results

This in vitro study aimed to evaluate and compare the surface roughness of aramid fiber-reinforced polymethyl methacrylate (PMMA) intended for use in denture bases. A total of 30 samples were prepared and divided into three groups: Group I, Group II, and Group III, with each group containing 10 samples. Statistical analysis was conducted using SPSS version 27. Descriptive statistics were used to determine the mean and standard deviation, and a one-way ANOVA was performed for group comparison. A p-value of 0.039 was considered statistically significant. [Table 1]

Statistical analysis was performed using **SPSS version 27**, applying descriptive statistics and one-way ANOVA to compare surface roughness values among the groups. A statistically significant difference was observed between the groups (**p = 0.039**), [Table 2, 3] indicating that aramid pulp reinforcement alters the surface characteristics of PMMA, with different concentrations producing varied outcomes.

Table 1: Descriptive statistics of the specimen and various groups for surface roughness

	N	Mean ± SD	Standard Error	95% Confidence Interval		Minimum	Maximum
				Lower bound	Upper bound		
Group 1 - Control group (Pink)	10	0.674 ± 0.363	0.114	0.415	0.933	0.22	1.056
Group 2 - 5% Aramid-Reinf	10	1.065 ± 0.	0.145	0.736	1.394	0.156	1.66

orced with PMMA		460					
Group 3 - 10%Aramid - Reinforced with PMMA	10	0.982 ± 0.059	0.019	0.939	1.024	0.876	1.078

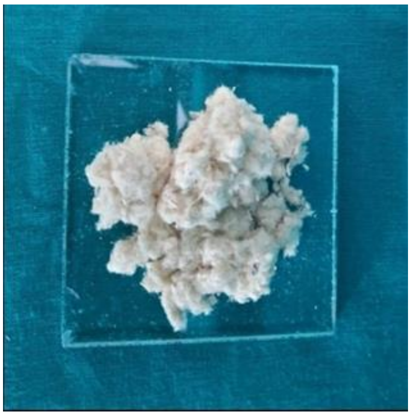


Figure 3: Group I: PMMA, Group II: 5% aramid reinforced PMMA;

Group III: 10% aramid reinforced PMMA

The study evaluated the impact of an additive on PMMA composites by analyzing mean values, standard deviations, confidence intervals, and value ranges. For pure PMMA (n=10), the mean surface roughness was 0.674 with a standard deviation of ±0.363. The 95% confidence interval ranged from 0.415 to 0.933, and the surface roughness values varied between 0.220 and 1.056. With the addition of 5% aramid fiber, the mean surface roughness increased to 1.065, accompanied by greater variability (±0.460). The confidence interval expanded to 0.736–1.394, and the values ranged from 0.156 to 1.660, indicating a broader spread. In contrast, incorporating 10% aramid fiber resulted in a slightly lower mean of 0.982 with a much smaller standard deviation (±0.059). The confidence interval narrowed to 0.939–1.024, and the range of values, from 0.876 to 1.078, suggested more uniformity compared to the 5% aramid fiber group.

Table 2: Analysis of Surface Roughness Between And Within Groups

	Sum of squares	df	Mean square	F	P value
Between groups	0.850	2	0.425	3.683	0.039*
Within groups	3.114	27	0.115		
Total	3.964	29			

The ANOVA results indicate a statistically significant difference in surface roughness among the groups, with an F-value of 3.683 and a p-value of 0.039, which is below the 0.05 significance level. This suggests that the incorporation of aramid pulp into PMMA composites significantly affects surface roughness. The mean square value between groups (0.425) is notably higher than the mean square within groups (0.115), indicating greater variation between the groups compared to within each group. Consequently, it can be concluded that surface roughness varies significantly among the control group and the two aramid-reinforced PMMA groups, emphasizing the influence of fiber reinforcement on the material's surface characteristics.

Table 3 Post hoc Bonferroni multiple comparisons test of samples within the groups

I (Group)	J (Group)	Mean Difference (I-J)	95% Confidence Interval		P value
			Lower bound	Upper bound	
1 (Control)	2 (5%)	-0.391	-0.779	-0.004	0.047*

	3 (10%)	-0.308	-0.696	0.080	0.153
2 (5%)	3 (10%)	0.084	-0.304	0.471	1.00

The table presents the statistical comparisons among three groups: Group 1 (Control), Group 2 (5% aramid pulp), and Group 3 (10% aramid pulp). A significant mean difference of -0.391 was observed between Group 1 and Group 2, with a p-value of 0.047, indicating a statistically significant difference. In contrast, the comparison between Group 1 and Group 3 showed a mean difference of -0.308 and a p-value of 0.153, which was not statistically significant. Likewise, the comparison between Group 2 and Group 3 revealed a mean difference of 0.084 with a p-value of 1.000, also indicating no significant difference. Thus, the only statistically significant difference was found between the Control group and the 5% aramid pulp group.

5. Discussion

Evaluating the surface roughness of materials for dental prostheses is essential, as rough surfaces can lead to issues such as discoloration, patient discomfort, and an increased risk of bacterial and fungal growth. The roughness can enhance the adhesion of microorganisms, promoting biofilm formation.[10]

The texture of denture base materials is influenced by factors like chemical composition, reinforcing materials, and polymerization techniques. Smoother surfaces are more aesthetically pleasing, less prone to staining, and less likely to harbor microorganisms like *Candida albicans*. The inner surface roughness of denture bases should not exceed 0.2 µm to prevent plaque buildup and microbial colonization.[11]

This study explored the effect of two different concentrations of aramid pulp on the surface roughness of polymethyl methacrylate (PMMA) composites. Surface roughness is vital in determining the performance and effectiveness of materials, especially in fields like dentistry, orthopedics, and engineering.

Narde J et al compared the color stability and surface roughness of PMMA and indirect composite resins after aging, finding that PMMA showed more discoloration and increased surface roughness, whereas indirect composite resins exhibited better stability, making them more reliable for long-term restorations.[12]

In this study, the effect of various additives on the surface roughness of polymethyl methacrylate (PMMA) composites was examined. The control PMMA group had a mean surface roughness of 0.674 µm, with a standard deviation of ±0.363 µm and a 95% confidence interval of 0.415–0.933 µm. The addition of 5% aramid pulp increased the mean roughness to 1.065 µm, with greater variability (±0.460 µm) and a confidence interval of 0.736–1.394 µm. Adding 10% aramid pulp slightly reduced the mean surface roughness to 0.982 µm, with a narrower confidence interval of 0.939–1.024 µm, indicating more consistency. Although the additives altered the surface roughness, the changes were not statistically significant, highlighting the importance of careful surface analysis when modifying PMMA composites.

Belkheir M et al. explored the mechanical properties of PMMA reinforced with carbon, glass, and aramid fibers for potential optical fiber applications. Their study, using a genetic algorithm for simulation, revealed that the interface between glass/PMMA and aramid/PMMA composites experienced significant degradation, while the carbon/PMMA composite showed less degradation, emphasizing the reinforcing effect of carbon fiber on the polymer matrix.[13]

Morel LL et al. evaluated the mechanical, surface, and optical properties of 3D-printed resin for removable prostheses reinforced with 5% aramid fibers. Their findings showed that aramid fibers improved the elastic modulus, flexural strength, and surface free energy, without significantly affecting surface hardness, roughness, or color, which remained below the perceptibility threshold. This suggests that aramid fiber reinforcement enhances the resin's mechanical properties while maintaining its aesthetic qualities, making it suitable for durable denture bases.[14]

Nayan K et al. evaluated the impact of thermocycling on the flexural strength of acrylic denture base materials reinforced with glass, carbon, aramid fibers, and high-impact resins. The study found that all reinforced materials exhibited better flexural strength compared to conventional acrylic resin. Among them, glass fiber

reinforcement provided the highest strength, followed by high-impact resin, carbon, and aramid fibers, making glass fiber-reinforced acrylic particularly suitable for dentures subjected to heavy masticatory loads.[15]

Lee SI examined the impact of short glass fibers on the transverse strength and surface roughness of heat-polymerized denture base acrylic resin. Glass fibers were added at concentrations of 0%, 3%, 6%, and 9% by weight. The study found that adding 6% and 9% glass fibers significantly improved transverse strength, while surface roughness remained largely unchanged for 0%, 3%, and 6% fiber concentrations. SEM images revealed increased roughness where fiber bunching occurred. Overall, the study concluded that incorporating 6% and 9% glass fibers enhanced strength without significantly affecting surface roughness.[16]

In this study it was observed that the surface roughness of PMMA modified with varying concentrations of aramid pulp. The addition of 5% aramid pulp increased the mean surface roughness to 1.065 µm, indicating greater variability, while 10% aramid pulp slightly reduced the mean to 0.982 µm, with more consistency. Although the differences between 5% and 10% aramid pulp were notable, they were not significant compared to the control PMMA, suggesting the need for further studies on higher concentrations of aramid pulp. The research emphasizes the importance of systematic evaluation of additives to optimize PMMA for diverse applications. However, the study was limited to laboratory conditions and did not consider factors like mouth temperature, oral biofilm interaction, or residual monomer toxicity. Future research should explore more realistic clinical conditions to better understand the material's behaviour in practical settings.

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