Comparative Evaluation of Impact Strength and Surface Hardness for Heat Cured Polymethylmethacrylate Denture Base Resin Reinforced with Different Particle Size and Concentration of Hexagonal Boron Nitride Particles: An Invitro Study

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Abstract— **"Comparative Evaluation of Impact Strength and Surface Hardness for Heat Cured Polymethylmethacrylate Denture Base Resin Reinforced with Different Particle Size and Concentration of Hexagonal Boron Nitride Particles: An Invitro Study"**

Background and Objectives:
Polymethyl methacrylate (PMMA) is widely used for denture base fabrication due to its good esthetics, biocompatibility, and ease of processing. However, it exhibits low impact strength and moderate surface hardness, which may lead to denture fracture and wear. Incorporation of hexagonal boron nitride (h-BN) particles has been explored to reinforce PMMA and improve its impact strength and surface hardness, thereby enhancing the durability of denture base resins. The aim of the present study was to compare and evaluate the impact strength and surface hardness of different concentrations and particle sizes of hexagonal boron nitride particles on heat cured polymethyl methacrylate denture base resin.

Materials and Method:
144 samples were prepared with dimensions 65x10x3mm (ISO 1567). These samples were grouped into Group A and B (control groups) containing 8 samples each. Remaining 128 samples were divided into 16 groups according to the concentrations and particle sizes of h-BN. Group N_1: 1% wt. of chemically synthesized h-BN nanoparticles, Group N_2: 1.5% wt. of chemically synthesized h-BN nanoparticles, Group N_3: 3% wt. of chemically synthesized h-BN nanoparticles, Group N_4: 5% wt. of chemically synthesized h-BN nanoparticles, Group M_1: 1% wt. of chemically synthesized h-BN microparticles, Group M_2: 1.5% wt. of chemically synthesized h-BN microparticles, Group M_3: 3% wt. of chemically synthesized h-BN microparticles, Group M_4: 5% wt. of chemically synthesized h-BN microparticles, for impact strength testing. Group N_5: 1% wt. of chemically synthesized h-BN nanoparticles, Group N_6: 1.5% wt. of chemically synthesized h-BN nanoparticles, Group N_7: 3% wt. of chemically synthesized h-BN nanoparticles, Group N_8: 5% wt. of chemically synthesized h-BN nanoparticles, Group M_5: 1% wt. of chemically synthesized h-BN microparticles, Group M_6: 1.5% wt. of chemically synthesized h-BN microparticles, Group M_7: 3% wt. of chemically synthesized h-BN microparticles, Group M_8: 5% wt. of chemically synthesized h-BN microparticles, for surface hardness testing. Samples were subjected to impact strength and surface hardness testing. Obtained values were analysed statistically using one-way ANOVA and Tukey's Post Hoc test.

Results:
The mean impact strength was highest in Group M_2 (2.13 kJ/m²), followed by Group N_3 (1.32 kJ/m²), Group N_2 (1.275 kJ/m²), Group M_1 (1.26 kJ/m²), Groups N_1 and M_3 (1.18 kJ/m²), Groups N_4 and A (1.10 kJ/m²), while the lowest value was observed in Group M_4 (1.03 kJ/m²).
With respect to surface hardness, the highest mean value was observed in Group N_7 (23.19 kgf/mm²), followed by Group M_7 (22.64 kgf/mm²), Group M_6 (21.59 kgf/mm²), Group M_5 (21.24 kgf/mm²), Group N_6 (20.79 kgf/mm²), Group N_5 (20.51 kgf/mm²), and Group B (20.33 kgf/mm²). Lower values were noted for Group N_8 (19.38 kgf/mm²), with the least surface hardness recorded in Group M_8 (18.99 kgf/mm²).

Conclusion:
The incorporation of chemically synthesized hexagonal

boron nitride (h-BN) particles significantly improved the mechanical properties of heat-cured PMMA denture base resin. Although 3 wt% h-BN microparticles demonstrated slightly higher surface hardness, the difference with the other concentrations was not statistically significant. However, 1.5 wt% h-BN microparticles showed a notable leap in impact strength, which is a critical property in preventing denture fracture during functional use or accidental dropping. Therefore, considering the comparable surface hardness and the substantial improvement in impact strength, incorporation of 1.5 wt% h-BN microparticles in PMMA denture base resin may be considered the most favorable concentration for potential clinical application.

***Index Terms*—Heat-cured PMMA; Chemically synthesized hexagonal boron nitride; h-BN nanoparticles; h-BN microparticles; Impact strength; Surface hardness.**

I. INTRODUCTION

Edentulism is a debilitating and irreversible condition and has been described as the final marker of disease burden for oral health. [1] Individuals suffering from edentulism exhibit a variety of physical and physiological changes that may adversely affect oral function and overall well-being. Loss of teeth compromises essential oral functions such as mastication and speech, and often results in compromised facial esthetics, which in turn negatively influences the patient's quality of life. [2]

For the rehabilitation of edentulous patients, complete dentures fabricated using polymethyl methacrylate (PMMA) acrylic resins have remained the most widely used treatment modality for more than seven decades. [3] PMMA continues to be a popular denture base material due to its favorable properties, including good esthetics, optical clarity, biocompatibility, ease of processing, repairability, and cost-effectiveness. [4] Despite these advantages, PMMA denture base resins are not considered ideal materials because of certain inherent limitations related to their mechanical and physical properties. [5]

One of the major drawbacks of PMMA is its relatively low resistance to impact, fatigue, and flexural stresses, which may lead to fracture of the denture during clinical use or accidental dropping.[6] Conventional PMMA tends to behave as a brittle material when subjected to sudden impact forces, making denture fracture a common clinical complication.[7] Consequently, numerous studies have focused on improving the mechanical properties of acrylic denture base resins, particularly their impact strength, fatigue resistance, and transverse strength.[8]

Several reinforcement methods have been investigated to enhance the strength of acrylic resins, including the incorporation of carbon fibers, glass fibers, ultra-high molecular weight polyethylene fibers, and metal powders .[9] However, the use of metallic reinforcements can adversely affect the esthetic properties of the denture base material and may not chemically bond effectively with the resin matrix.[10] Glass fibers have shown promise because they can chemically bond to resin materials following silane treatment and meet esthetic requirements. Nevertheless, difficulties in achieving homogeneous dispersion of fibers within the resin matrix may result in inadequate fiber impregnation and inconsistent reinforcement. [11]

With advancements in material science, the use of nanotechnology in dentistry has opened new avenues for improving the performance of dental biomaterials. [12] Incorporation of micro- and nano-scale particles into polymer matrices has been shown to enhance stiffness, strength, wear resistance, and other mechanical properties without significantly compromising esthetics or handling characteristics. [13]

Among the emerging reinforcing materials, boron-based compounds have gained considerable attention in both medical and material science fields. Hexagonal boron nitride (h-BN), often referred to as "white graphene" due to its structural similarity to graphene, possesses several desirable properties such as excellent mechanical strength, high thermal stability, chemical inertness, electrical insulation, and good biocompatibility. [14]

Boron nitride nanoparticles (BNNPs) appear as a white powder and therefore do not compromise the esthetic appearance of dental materials, making them particularly suitable for dental applications.[15] Boron nitride has been investigated in various areas of dental research, including reinforcement of dental ceramics, filler material in resin-based dental sealants, improvement of dental adhesive systems, coatings for dental implants, and as fillers in dental resin

composites.[16] Studies have demonstrated that incorporation of non-covalently functionalized boron nitride nanoflakes into PMMA matrices can significantly increase the elastic modulus and ultimate tensile strength of the polymer while also improving its toughness.[17]

In addition to nanoparticles, boron nitride microparticles, particularly hexagonal boron nitride, have also attracted increasing interest as reinforcing fillers for dental materials. These microparticles possess a unique combination of mechanical, thermal, and biological properties. They exhibit high strength, excellent thermal conductivity, chemical stability, and a layered crystalline structure that provides solid-lubricating behavior, thereby reducing friction and wear in restorative materials.[18] When incorporated into polymer-based dental materials such as PMMA denture base resins, composite resins, and dental adhesives, boron nitride microparticles have been reported to improve flexural strength, hardness, wear resistance, and thermal conductivity without adversely affecting esthetics.[19] Furthermore, boron nitride has demonstrated good biocompatibility with minimal cytotoxicity, making it suitable for intraoral applications.[20]

Previous investigations have reported that PMMA reinforced with hexagonal boron nitride nanosheets exhibited a substantial improvement in mechanical performance, including nearly 70% increase in ultimate tensile strength and a significant enhancement in fracture toughness compared with conventional PMMA.[21] Functionalized h-BN particles have also been shown to improve surface hardness and thermal properties when incorporated into polymeric matrices.[22] Although several studies have explored the reinforcement of dental materials using boron nitride particles, research focusing on simultaneous improvement of both impact strength and surface hardness of PMMA denture base resins using hexagonal boron nitride nanoparticles and microparticles remains limited.

Therefore, the present study aims to evaluate the effect of incorporating different concentrations of hexagonal boron nitride nanoparticles and microparticles (1%, 1.5%, 3%, and 5% by weight) on the impact strength and surface hardness of commercially available heat-cured polymethyl methacrylate denture base resin.

II. METHODOLOGY

Effect of h-BN Nano & Microparticles on Impact Strength and Surface Hardness of Heat-Cured PMMA Denture Base Resin

1. Study Objective & Setting

An in-vitro study was conducted at the Department of Prosthodontics & Crown and Bridge, Sri Hasanamba Dental College and Hospital, Hassan, Karnataka. The aim was to evaluate and compare the effect of adding hexagonal boron nitride (h-BN) nanoparticles (30–50 nm) and microparticles (3–4 μm) at varying weight concentrations (1%, 1.5%, 3%, and 5%) on the impact strength and Vickers surface hardness of heat-cured PMMA denture base resin. Mechanical testing was carried out at Nanjangud, Mysuru district.

2. Armamentarium & Materials

Table 1: Key Armamentarium

Sl. No.	Instrument	Manufacturer
1	Acrylizing & Dewaxing Unit	Unident, India
2	Hydraulic Bench Press	Sirio, Italy
3	Izod Impact Testing Machine	Instron, USA
4	Vickers Hardness Tester (MDV 401)	Wilson Wolpert, Germany
5	Heavy Duty Lab Micromotor	Marathon, Korea
6	Digital Weighing Machine	SF 400 Kitchen Scale, India
7	Vernier Caliper	API, Germany
8	Flask, Clamp & Polishing Unit	Niyazan / Unident, India

Table 2: Key Materials

Sl. No.	Material	Brand / Manufacturer
1	Heat-Cure Denture Base Resin	DPI Heat Cure, Mumbai, India
2	h-BN Nanoparticles (30–50 nm)	Platonic Nanotech, Jharkhand
3	h-BN Microparticles (3–4 μm)	Platonic Nanotech, Jharkhand
4	Die Stone (Type IV) / Dental Plaster (Type II)	Kalrock / Sodaclays, India
5	Light Body Vinyl Polysiloxane	Aquasil Ultra, Dentsply, India
6	Cold Mould Seal / Petroleum Jelly	DPI / Bioline, India

7	Sand Paper (80, 100, 120 grit) / Pumice	Carborandam / DPI, India

3. Sample Preparation

3.1 Wax Pattern & Mould Fabrication

A master wax block (65 mm × 10 mm × 3 mm) conforming to ADA Specification No. 12 / ISO 1567:2002 was prepared from modelling wax. This block was boxed and a light-body vinyl polysiloxane impression material was injected around it to create a flexible mould. A die stone casing (cut into interlocking halves) provided external stability. Molten wax was poured into this mould to duplicate 144 identical wax samples, all verified with a Vernier caliper.

3.2 Incorporation of h-BN Particles into PMMA

h-BN nano and microparticles were soaked individually in monomer for 10 minutes to improve adhesion, then allowed to dry. The particles were weighed on a digital balance and blended with 100 g batches of PMMA polymer powder first by mortar and pestle, then by hand-tumbling in a plastic jar until uniform colour was achieved. The resin was then mixed with monomer to a dough consistency as per manufacturer's instructions.

Composition per group (100 g total):

- 1% groups: 99 g PMMA + 1 g h-BN
- 1.5% groups: 98.5 g PMMA + 1.5 g h-BN
- 3% groups: 97 g PMMA + 3 g h-BN
- 5% groups: 95 g PMMA + 5 g h-BN
- Control groups (A & B): 100 g PMMA only (no filler)

3.3 Flasking & Curing

Wax samples were invested in dental plaster, followed by counter-flasking with die stone. Dewaxing was carried out by immersing flasks in boiling water for 10 minutes. After cooling, cold mould seal was applied. Flasks were packed with PMMA dough at dough consistency and pressed on a hydraulic bench press. Trial packing was done to remove flash and clamps were tightened.

Curing cycle: bench cure 45 min → short curing at 74°C for 2 hours → boiling at 100°C for 1 hour. Flasks were bench-cooled for 30 min and then under running tap water for 5 min before retrieval.

3.4 Finishing & Storage

Flash was trimmed using tungsten carbide burs (extra coarse to fine) with light pressure. Surfaces were finished progressively with sandpaper (80, 100, 120 grit) and polished using pumice slurry on a wet buff lathe. Final dimensions were verified by Vernier caliper. All 144 samples were stored in distilled water at 37°C for 48 hours prior to testing.

4. Study Groups

A total of 144 samples were divided into 18 groups (n = 8 each). Separate sets were used for impact strength (72 samples) and surface hardness (72 samples).

Test	Control	1% h-BN	1.5% h-BN	3% h-BN	5% h-BN
Impact Strength Surface hardness	Group A (Control)	Nano: N1 Micro: M1	Nano: N2 Micro: M2	Nano: N3 Micro: M3	Nano: N4 Micro: M4
	Group B (Control)	Nano: N5 Micro: M5	Nano: N6 Micro: M6	Nano: N7 Micro: M7	Nano: N8 Micro: M8

N = Nanoparticles (30–50 nm); M = Microparticles (3–4 μm); n = 8 per group

5. Testing Methods

5.1 Impact Strength (Charpy/Izod Method)

Testing was performed at room temperature using an Izod impact testing machine (Instron, USA). Specimens were horizontally positioned with a 40 mm span between two fixed supports. A 0.5 J pendulum striker was used.

$a_{cu} = (E_c / hb) \times 10^3$

- acu = Charpy impact strength of unnotched specimen (kJ/m²)
- Ec = corrected energy absorbed by breaking the specimen (J)
- h = thickness of specimen (mm); b = width of specimen (mm)

5.2 Vickers Surface Hardness

Testing was performed using a Vickers Hardness Tester (Model MDV 401, Wilson Wolpert, Germany). A 50 g load was applied via a diamond indenter for 10 seconds at three distinct points on each specimen

surface, maintaining at least 2 mm between indentations.

$VHN = 1.854 L / d^2$

- VHN = Vickers Hardness Number (kg/mm²)
- L = applied load (kg)
- d = mean length of the indentation diagonals (mm)

6. Statistical Analysis

All data were analysed using SPSS for Windows (Version 20.0). The following tests were applied:

- Kruskal-Wallis Test — non-parametric overall group comparison
- One-Way ANOVA — parametric comparison of group means
- Tukey's HSD Post Hoc Test — pairwise multiple comparisons (applied when F-test was significant)
- Statistical significance threshold: $p < 0.05$

Mean and Standard Deviation were used as descriptive statistics. The Tukey critical value was calculated and compared against all pairwise mean differences to identify significant group contrasts.

7. Methodology Summary Flow

1. Prepare 144 wax patterns (65×10×3 mm) using standardised silicone mould
2. Weigh h-BN particles; soak in monomer 10 min; blend with PMMA polymer
3. Flask, dewax, pack resin in dough stage, hydraulic press
4. Cure: 74°C × 2 hr → 100°C × 1 hr → bench cool → water cool
5. Trim, finish (burs + sandpaper 80/100/120 grit), polish (pumice)
6. Verify dimensions (Vernier caliper); store in distilled H_2O at 37°C for 48 hr
7. Impact Strength: Izod/Charpy machine, 0.5 J pendulum, 40 mm span (n=72)
8. Surface Hardness: Vickers tester, 50 g load, 10 sec, 3 points/sample (n=72)
9. Statistical analysis: Kruskal-Wallis → One-Way ANOVA → Tukey's HSD

8. Key Experimental Parameters

Parameter	Detail
Sample dimensions	65 mm × 10 mm × 3 mm
Standard followed	ADA Spec. No. 12 / ISO 1567:2002
Total samples	144 (n = 8 per group, 18 groups)
Filler types	h-BN nanoparticles (30–50 nm) and microparticles (3–4 µm)
Concentrations	1%, 1.5%, 3%, 5% by weight
Storage before testing	Distilled water, 37°C, 48 hours
Curing protocol	45 min bench → 74°C/2 hr → 100°C/1 hr
Impact test pendulum	0.5 J; span 40 mm; room temperature
Hardness test load	50 g; 10 sec dwells; 3 indentations/sample
Statistical software	SPSS v20.0 for Windows

III. RESULT

Impact Strength & Vickers Hardness of h-BN Reinforced Acrylic Resin

Study Overview

Eighteen groups of heat-cure acrylic resin were tested: nano-h-BN and micro-h-BN particles at 1.0%, 1.5%, 3.0%, and 5.0% wt concentrations, plus an unreinforced control. Statistical significance was set at $p < 0.05$. All pairwise comparisons were evaluated using Tukey's HSD post hoc test following significant Kruskal-Wallis and one-way ANOVA results ($p < 0.001$).

I. Impact Strength (J/cm²)

Group	Mean (J/cm²)	Std. Dev.
1.0% Nano	1.1800	0.305
1.5% Nano	1.2750	0.083
3.0% Nano	1.3188	0.052
5.0% Nano	1.0963	0.141
1.0% Micro	1.2588	0.021
1.5% Micro	2.1263*	0.125
3.0% Micro	1.1813	0.167
5.0% Micro	1.0250	0.092
Control	1.0988	0.227

* Highest value in category

Key Findings

Nano-h-BN: Impact strength improves progressively from 1.0% to 3.0% (optimal). The 3.0% Nano group significantly outperformed 5.0% Nano ($p=0.001$) and Control ($p=0.012$). At 5.0%, performance drops to near-control levels ($p=0.752$ vs. Control), indicating filler agglomeration.

Micro-h-BN: 1.5% Micro was markedly superior to all other groups (mean 2.1263 J/cm²), with highly significant differences vs. all nano concentrations (p=0.001 each) and vs. Control (p=0.001). Above 1.5%, micro reinforcement declines sharply; 3.0% and 5.0% Micro show no significant difference from Control.

Conclusion: 1.5% Micro-h-BN gives the highest impact strength overall; 3.0% Nano-h-BN is optimal within nano groups.

II. Vickers Surface Hardness (HV)

Group	Mean (HV)	Std. Dev.
1.0% Nano	20.51	1.513
1.5% Nano	21.79	0.646
3.0% Nano	23.19*	0.409
5.0% Nano	19.38	1.487
1.0% Micro	21.24	0.730
1.5% Micro	21.59	0.707
3.0% Micro	22.64	1.100
5.0% Micro	19.37	1.276
Control	20.83	0.981

* Highest value in category

Key Findings

Nano-h-BN: 3.0% Nano achieved the highest hardness (23.19 HV), significantly greater than 1.0% Nano (p=0.001), 1.5% Nano (p=0.003), and 5.0% Nano (p=0.001). At 5.0%, hardness falls to control levels (p=0.059 vs. Control), confirming a non-linear response with 3.0% as the optimal loading.

Micro-h-BN: 3.0% Micro was the optimal concentration (22.64 HV), significantly harder than 1.0% Micro (p=0.016), 5.0% Micro (p=0.002), and Control (p=0.007). Lower concentrations (1.0% and 1.5% Micro) did not differ significantly from Control. 5.0% Micro was also not significantly different from Control (p=0.052).

Nano vs. Micro at 3.0%: No significant difference between 3.0% Nano and 3.0% Micro (p=0.493) — both achieve comparable surface hardness at this concentration.

Conclusion: 3.0% concentration is optimal for both nano and micro-h-BN for surface hardness. Excessive filler (5.0%) diminishes hardness regardless of particle size.

Overall Summary

Best for impact strength: 1.5% Micro-h-BN (2.1263 J/cm²) — far exceeds all other groups.

Best for surface hardness: 3.0% Nano-h-BN (23.19 HV) and 3.0% Micro-h-BN (22.64 HV) both statistically comparable.

Common finding: 5.0% filler loading (both nano and micro) consistently reduces mechanical properties to near-control levels, likely due to filler agglomeration and compromised polymer matrix integrity.

IV. DISCUSSION

1. Background: Edentulism & Prosthodontic Rehabilitation

Edentulism — complete loss of natural teeth remains a major global oral health concern, arising from dental caries, periodontal disease, trauma, and systemic conditions. Beyond oral dysfunction, tooth loss leads to compromised mastication, impaired speech, nutritional deficiencies, and significant psychosocial consequences including reduced self-esteem and social confidence. Its prevalence rises with age and socioeconomic disadvantage, representing a significant public health challenge.

Removable prostheses are a primary, cost-effective rehabilitation modality for edentulous patients. They restore masticatory function, speech, facial contour, and esthetics — improving oral health-related quality of life. They are especially important in developing countries and for elderly patients unsuitable for implant therapy.

2. PMMA as Denture Base Material

Polymethyl methacrylate (PMMA) has been the material of choice for denture base fabrication since its introduction. Its advantages include:

- Favourable esthetics and translucency
- Ease of manipulation and processing
- Relatively low cost and acceptable biocompatibility

However, conventional heat-cured PMMA has notable mechanical limitations:

- Low impact strength: predisposes to midline fractures and catastrophic failure from accidental dropping or flexural fatigue during mastication
- Moderate surface hardness: insufficient resistance to wear and scratching, leading to increased surface roughness, plaque accumulation, and reduced prosthesis longevity

Beyli & Von Fraunhofer[62] (1981) first documented that PMMA's inherent brittleness and poor impact

resistance are primary contributors to denture fracture in clinical practice, emphasising the need for reinforcement strategies.

3. Rationale for Reinforcement with h-BN

To overcome PMMA's limitations, various reinforcing agents have been investigated, including ZrO_2, TiO_2, Al_2O_3, SiO_2 nanoparticles, glass fibers, and carbon nanotubes. These materials show varying improvements in impact strength, flexural strength, and surface hardness — but an ideal filler that enhances multiple properties simultaneously without compromising PMMA's physical and biological characteristics remains elusive.

Hexagonal boron nitride (h-BN) — often called "white graphene" — has emerged as a highly promising reinforcing nanomaterial, distinguished by:

- Exceptional mechanical strength and hardness
- Excellent thermal stability and chemical inertness
- Favourable biocompatibility
- Layered hexagonal crystal structure enabling efficient load transfer and stress distribution within polymer matrices

h-BN particles act as crack deflectors and energy absorbers, limiting crack initiation and propagation. Their nanoscale dimensions provide high surface-area-to-volume ratios that promote stronger interfacial bonding with the PMMA matrix, thereby increasing load-bearing capacity. However, excessive filler concentrations can cause particle agglomeration, adversely affecting mechanical properties — making optimal concentration determination critical.

4. Supporting Literature

Author (Year)	Study	Key Finding
Alqahtani M[29] (2020)	h-BN into PMMA (ultrasonic mixing)	Hardness ↑ up to 300%; flexural strength ↑ significantly
Hussein et al[38] (2023)	BN nanoparticles in heat-cured PMMA	Impact strength ↑ significantly at 1.5% BN vs control
Lee B et al[28] (2020)	BN nanoplatelets (BNNPs) in dental material	Strength ↑ 27.3%; fracture toughness ↑ 37.5% at 1.5 vol%
Wang H et al[21] (2019)	Nano-h-BN in PMMA bone cement	Bending stress ↑ 26% at 3 wt%; Vickers hardness ↑ ~90%
Gopalan V et al[44] (2025)	h-BN in epoxy polymer composites	Highest impact strength at 3.95 wt% h-BN (0.32 kJ/m²)
Beyli & Von Fraunhofer[62](1981)	Fracture analysis of acrylic dentures	PMMA brittleness & low impact resistance → midline fractures

5. Present Study: Impact Strength Findings

5.1 Test Protocol

Impact strength was evaluated using the Charpy method in an Izod impact testing machine (Instron, USA). Specimens (65×10×3 mm) were horizontally positioned with a 40 mm span and tested at room temperature using a 0.5 J pendulum.

5.2 Key Results

Group M2 (1.5 wt% micro h-BN) demonstrated the highest impact strength of 2.13 kJ/m² — nearly double that of the control group (1.10 kJ/m²). This difference was statistically significant.

Performance trend across groups:

- 1.5% Micro h-BN: Best overall (2.13 kJ/m²) — optimal particle dispersion facilitates efficient stress transfer and energy absorption
- 3.0% Nano h-BN: Best among nano groups (1.32 kJ/m²); significantly outperformed 1.0%, 5.0% Nano, and Control
- 5.0% Nano & 5.0% Micro: Impact strength reverted to near-control levels — attributed to filler agglomeration and compromised polymer matrix integrity
- 3.0% & 5.0% Micro: Not significantly different from Control reinforcement benefit lost above 1.5% micro loading

5.3 Explanation & Agreement with Literature

The superior performance of 1.5 wt% microparticles is attributed to optimal filler dispersion enabling effective stress transfer. At higher concentrations (≥3%), particle clustering creates stress concentration sites that reduce reinforcing efficiency. These findings align with Lee B et al[28] (2020), Hussein et al[38] (2023),

Ozdemir AK et al[32] (2021), Li Met al[37] (2022), and Alqahtani M[29] (2020), all of whom reported that 1–3 wt% filler concentrations provide superior mechanical strength, while 5 wt% concentrations reduce performance due to agglomeration.

6. Present Study: Surface Hardness Findings

6.1 Test Protocol

Surface hardness was measured using a Vickers Hardness Tester (Wilson Wolpert, Germany). A 50 g load was applied via diamond indenter for 10 seconds at three points per specimen (≥2 mm apart).

6.2 Key Results

Group N7 (3 wt% nano h-BN) exhibited the highest surface hardness (23.19 HV), significantly greater than all other groups.

Performance trend across groups:

- 3.0% Nano h-BN: Highest hardness (23.19 HV); significantly better than 1.0% Nano (p=0.001), 1.5% Nano (p=0.003), 5.0% Nano (p=0.001), and Control (p=0.001)
- 3.0% Micro h-BN: Second best (22.64 HV); comparable to 3.0% Nano (p=0.493, not significant) optimal micro loading for hardness
- 5.0% Nano & 5.0% Micro: Hardness fell to near-control levels non-uniform nanoparticle distribution due to agglomeration negates reinforcement benefit
- 1.0% & 1.5% Micro: Not significantly different from Control insufficient loading for meaningful hardness enhancement

6.3 Mechanism & Agreement with Literature

The hardness improvement at 3 wt% nano h-BN is explained by the intrinsic rigidity of boron nitride, the high surface-area-to-volume ratio of nanoparticles promoting stronger interfacial bonding, and well-distributed nanoparticles restricting polymer chain mobility to increase resistance to plastic deformation. These findings are consistent with Alqahtani M[29] (2020), Lee B et al[28] (2020), Wang H et al[21] (2019), Li Met al[37] (2022), and Hussein et al[38] (2023), all reporting significant hardness improvements at optimal h-BN concentrations.

7. Integrated Findings & Clinical Significance

Parameter	Optimal Group	Value	vs. Control
Impact Strength	1.5% Micro h-BN	2.13 kJ/m²	~94% higher (p<0.001)
Surface Hardness	3.0% Nano h-BN	23.19 HV	Significantly higher (p<0.001)
Both properties combined	1.5% Micro h-BN	—	Best overall clinical candidate

The present study demonstrates that incorporating h-BN particles into heat-cured PMMA denture base resin significantly enhances its mechanical properties. Key conclusions:

- 1.5 wt% micro h-BN produced the maximum impact strength — almost double that of the control — making it the most favorable concentration for clinical application where fracture resistance is paramount
- 3.0 wt% nano h-BN produced the highest surface hardness, reducing susceptibility to wear, surface roughness, and plaque accumulation over time
- 5.0 wt% loading of both nano and micro h-BN consistently reduced mechanical performance to near-control levels, underscoring that excessive filler loading is counterproductive
- Enhanced clinical durability: h-BN reinforced PMMA is expected to reduce denture fracture incidence, improve wear resistance, and extend prosthesis longevity

8. Limitations & Future Directions

This investigation was conducted under in vitro conditions using standardised laboratory specimens. Results should be interpreted with caution as in vitro findings may not fully replicate the complex mechanical and biological oral environment. The following are recommended for future research:

- In vivo clinical studies to assess real-world performance and patient satisfaction
- Long-term evaluations of biocompatibility, colour stability, and dimensional accuracy
- Assessment of surface roughness and plaque adhesion properties of h-BN reinforced PMMA
- Investigation of alternative mixing methods (e.g., ultrasonic dispersion) to optimise particle distribution and further enhance properties

- Exploration of combined fillers (e.g., h-BN with zirconia or glass fibers) for synergistic reinforcement

Conclusion

The incorporation of 1.5 wt% h-BN microparticles into heat-cured PMMA denture base resin produces the most clinically significant improvement in impact strength, while 3.0 wt% h-BN nanoparticles yield slightly enhanced surface hardness. Therefore, we can conclude that incorporation of 1.5 wt % h-BN microparticles into PMMA denture base resin improves impact strength significantly as well as surface hardness and can be considered the most favorable concentration for clinical application. Further in vivo and long-term clinical research is required before establishing routine clinical protocols.

V. CONCLUSION

The present study was conducted to evaluate and compare the effect of different particle sizes and concentrations of hexagonal boron nitride (h-BN) particles on the impact strength and surface hardness of heat-cured polymethyl methacrylate (PMMA) denture base resin. Based on the analysis of the results obtained and within the limitations of the study, the following conclusions were drawn:

1 The impact strength of heat-cured PMMA denture base resin significantly increased after reinforcement with 1 wt%, 1.5 wt%, and 3 wt% hexagonal boron nitride nanoparticles (30–50 nm grain thickness) when compared with the control group (PMMA denture base resin without h-BN).
2 The impact strength of heat-cured PMMA denture base resin also significantly increased after reinforcement with 1 wt%, 1.5 wt%, and 3 wt% hexagonal boron nitride microparticles (3–4 μm grain thickness) when compared with the control group.
3 Among all the experimental groups, the incorporation of 1.5 wt% hexagonal boron nitride microparticles (3-4 μm grain thickness) into heat-cured PMMA denture base resin demonstrated the highest impact strength.
4 The incorporation of 5 wt% hexagonal boron nitride microparticles (3–4 μm grain thickness) into heat-cured PMMA denture base resin showed the lowest impact strength among the experimental groups.
5 The surface hardness of heat-cured PMMA denture base resin increased after reinforcement with 1 wt%, 1.5 wt%, and 3 wt% hexagonal boron nitride nanoparticles (30–50 nm grain thickness) when compared with the control group.
6 The surface hardness of heat-cured PMMA denture base resin also increased after reinforcement with 1 wt%, 1.5 wt%, and 3 wt% hexagonal boron nitride microparticles (3–4 μm grain thickness) compared with the control group.
7 The incorporation of 3 wt% hexagonal boron nitride nanoparticles (30–50 nm grain thickness) into heat-cured PMMA denture base resin exhibited slightly higher surface hardness among all the groups.
8 The incorporation of 5 wt% hexagonal boron nitride microparticles (3–4 μm grain thickness) into heat-cured PMMA denture base resin demonstrated the lowest surface hardness including the control group.

From the above observations, it was noted that incorporation of 1.5 wt% chemically synthesized hexagonal boron nitride (h-BN) microparticles (3-4 μm) into heat-cured polymethyl methacrylate (PMMA) denture base resin demonstrated the highest impact strength which was almost the double of those observed in other concentrations whereas addition of 3 wt% h-BN nanoparticles exhibited slightly higher surface hardness which was not statistically significance among the experimental groups.

Therefore, considering the remarkable improvement in impact strength and the comparable surface hardness, 1.5 wt% h-BN microparticle reinforcement can be regarded as the most favorable concentration for improving the mechanical performance of PMMA denture base resin for potential clinical use.

The materials and techniques evaluated in the present study were tested under in-vitro conditions, and therefore further in-vivo studies under clinical conditions are recommended to confirm these findings and to assess the long-term clinical performance and durability of PMMA denture base resins reinforced with hexagonal boron nitride nanoparticles and microparticles.

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