Uniosun Journal of Engineering and Environmental Sciences (UJEES), Vol. 8 No. 1, March, 2026
DOI: 10.64980/ujees.v8i1.006 **Diwe et al.**
Published: March 30, 2026

COMPARATIVE EVALUATION OF ZIRCONIA-, YSZ-, AND PORCELAIN-REINFORCED COLD-CURED PMMA DENTURE COMPOSITES

Ihuoma V. DIWE[1*], Olurotimi. A. ADELEYE[2], Henry E. MGBEMERE[3], Bolanle O. AKINBOBOYE[4]

[1,2]Department of Biomedical Engineering, University of Lagos, Nigeria
3Department of Metallurgical and Materials Engineering, University of Lagos, Nigeria
[4]Department of Restorative Dentistry, University of Lagos, Nigeria

[*]Corresponding Author: ivdiwe@unilag.edu.ng

Abstract
Polymethyl methacrylate (PMMA) has become a staple in dental applications. However, PMMA is inherently fragile and lacks sufficient mechanical strength for specific high-stress applications. To improve dental restorations and achieve long-lasting, appealing results, it is vital to develop denture composites with enhanced mechanical and physical properties. This study explores the mechanical properties of cold-cured PMMA denture composites reinforced with (1, 3, 5, and 7 wt. %) untreated zirconia (ZrO_2) nanoparticles, yttrium-stabilized zirconia (YSZ) nanoparticles, and dental porcelain. After the formulated PMMA powder, MMA monomer, and filler were invested in the mold formed in the dental flask and compacted with a hydraulic press, flexural strength, impact strength, hardness, and water absorption were evaluated. The results revealed an enhancement in the impact strength for all reinforced PMMA composites, with the highest value observed in the composites with 1 wt. % ZrO_2 NPs, YSZ, and porcelain particles marking a 3.50%, 3.04%, and 2.94% increase compared to pure PMMA, respectively. Hardness results for the composites containing 1 wt. % ZrO_2 NPs, 5 wt. %YSZ, and 5 wt. % porcelain particles showed the highest increase of 16.48%, 33.4%, and 14.26%, respectively. 7.37% and 64% enhancements in flexural strength were observed for both 1 wt. % ZrO_2 NPs, and YSZ, with a steady decrease for all wt. % of PMMA/porcelain composites when compared to the control sample. Generally, water absorption decreased for all reinforced PMMA composites after 48 hours. The best-performing filler overall was YSZ-NP, which exhibited enhanced mechanical properties and water absorption resistance.

Keywords
Dentures, Mechanical properties, Nanoparticles, PMMA, Water absorption

1. INTRODUCTION

For many individuals, complete dentures are not merely a replacement for missing teeth but a crucial component of their quality of life. Beyond the functional benefits of restored chewing efficiency, complete dentures address significant aesthetic concerns and psychosocial impacts associated with tooth loss. These concerns can range from a perceived decline in attractiveness to difficulties with speech and pronunciation, ultimately affecting self-confidence and social interactions [1]**.** Due to its desirable properties, Polymethyl methacrylate (PMMA) has become a staple in dental applications [2]. In dental clinics, PMMA is crucial for procedures such as relining dentures and crafting temporary crowns. Its importance continues in industrial settings, specifically in the production of artificial teeth [3]. However, PMMA is intrinsically fragile and lacks adequate mechanical strength for certain high-stress applications [4], [5]. The primary limitations of PMMA in dental applications include low fracture toughness, poor wear resistance, and limited mechanical strength. These drawbacks can lead to premature failure of dental restorations, posing challenges for clinicians and patients. Researchers have explored various methods to enhance PMMA's properties, including the incorporation of reinforcing agents [6], [7], [8]. Zirconia (ZrO_2) nanoparticles have been extensively researched for their ability to improve the mechanical properties of dental composites. Studies have demonstrated that incorporating zirconia nanoparticles can considerably enhance the fracture toughness, hardness, and wear resistance of polymer matrices [9]**.** Nevertheless, YSZ-NP exhibits properties distinct from zirconia nanoparticles, including high-temperature stability, chemical resistance, and improved mechanical properties [4].

Yttria-stabilized zirconia (YSZ) is a ceramic material usually used in a range of industrial applications owing to its distinctive properties. The name Yttria-Stabilized Zirconia is obtained from its composition, comprising zirconium dioxide (ZrO_2) that has been stabilized with yttrium oxide (Y_2O_3). The exact composition of YSZ varies, but it typically consists of 93% zirconia and 7% yttria. Yttria is added to zirconia to stabilize its crystal structure at room temperature. Devoid of yttria or other stabilizing agents, zirconia undergoes disorder-induced phase transformations, severely damaging the material [10]. YSZ exhibits specific properties that enhance its suitability for many dental applications [4]. These include high-temperature stability and resistance to thermal shock, making it appropriate for usage in harsh environments where other materials would fail. The material exhibits exceptional mechanical strength and hardness, which are well-suited to abrasive and high-stress environments [11]. It is generally considered biocompatible, making it an appropriate choice for dental applications [12].

Enhancement of stiffness and strength is attributed to the nanoparticles' ability to restrict polymer chain motion and increase the interfacial area between the matrix and the nanoparticles, thereby improving stress distribution. Additionally, nanoparticles can act as barriers to crack propagation, thus improving fracture toughness [13]**.** By incorporating nanoparticles such as silica, alumina, or zirconia, PMMA exhibits improved strength, stiffness, toughness, and impact resistance [14]. The large surface area of these nanoparticles promotes better interaction with the polymer matrix, resulting in enhanced load-bearing capacity and durability [15]**.** However, untreated nanoparticles, if well-dispersed, can also provide significant enhancements in mechanical properties [16]. The simplicity and cost-effectiveness of using untreated nanoparticles make them an attractive option for specific applications.

Zirconia is known for its exceptional hardness and toughness, which translates into increased tensile strength, flexural strength, and fracture toughness when used in dental materials [5], [16], [17], [18]. These enhanced mechanical properties are essential for dental restorations that must withstand the significant forces generated during chewing and grinding. Additionally, zirconia nanoparticles contribute to the composite's wear resistance, reducing material degradation over time and ensuring that the restoration remains functional and intact [19]. This is particularly crucial for the longevity and reliability of denture bases and other prosthetic components [20]; [21]. Recent studies have further validated the superior mechanical properties of zirconia-reinforced PMMA composites compared to those reinforced with other nanoparticles, such as silica or alumina, which indicated that zirconia-reinforced PMMA composites exhibit better resistance to crack propagation and higher surface hardness compared to silica or alumina-reinforced alternatives [22]**.**

Dental Porcelain has been used in dentistry for many years, primarily for its aesthetic properties, which can match the colour and translucency of natural teeth [23]**.** However, porcelain is more brittle than zirconia and can be prone to chipping or cracking under high stress [24]. Classification of dental porcelains is done based on their fusion temperature, microstructure, and processing technique [25]. Dental ceramics are made up of crystalline minerals, which include feldspar, quartz, alumina, and perhaps kaolin as a glass matrix [26]. Figure 1 shows a complete acrylic denture.

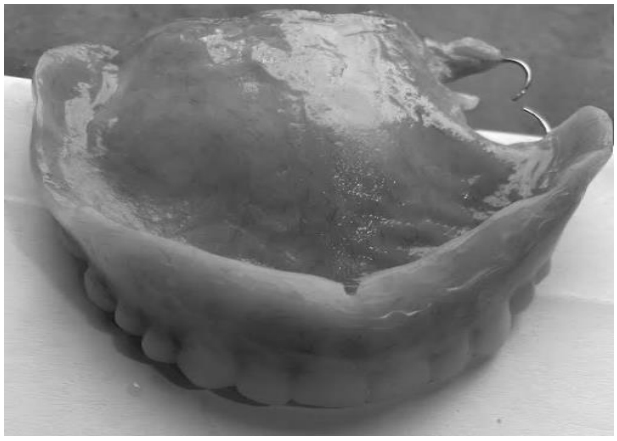

Figure 1: An image of a complete acrylic denture.

Exposure of PMMA denture base acrylics to oral environments for an extended time leads to water absorption, which adversely affects the mechanical and physical properties of the denture material, including its clinical effectiveness. Water absorption analysis has been shown to decrease with increasing weight percent of both reinforcing powders, peanut and walnut shells, in PMMA resin [27]. Further studies have

shown that the addition of ZrO_2 nanoparticles or E-glass fibres reduced the water sorption of the PMMA composites [28].

Cold curing, also known as ambient or room-temperature curing, is a process in which materials polymerize or harden at room temperature without external heat [29]. This method relies on the chemical reaction between a resin and a hardener or catalyst that occurs under ambient conditions [30]. It involves free-radical polymerization initiated by mixing a polymer powder (PMMA) with a liquid monomer (methyl methacrylate). Cold curing allows dental professionals to fabricate and repair restorations quickly, often within minutes. The process is straightforward and requires minimal equipment, making it ideal for both clinical and laboratory settings. It is also cost-effective because cold-curing materials are generally less expensive compared to heat-cured alternatives. Heat curing, as opposed to cold curing, involves polymerization at elevated temperatures, often in a water bath or oven. Heat-cured composites tend to exhibit excellent mechanical properties, including higher flexural strength, fracture toughness, and wear resistance [31]. These properties make heat-cured composites more suitable for permanent restorations, such as complete denture bases, where long-term durability is critical. However, heat curing requires more time, specialized equipment, and precise control over the curing environment, making it less convenient for certain clinical applications. Cold curing, on the other hand, is favoured for its convenience and rapid turnaround time, despite the trade-off in material performance.

Although there has been interest in reinforcing cold-cured Polymethyl Methacrylate (PMMA) composites with zirconia nanoparticles to enhance mechanical properties, there is little research specifically focused on this area. The challenges of achieving uniform nanoparticle dispersion and the lower mechanical performance of cold-cured materials relative to heat-cured counterparts have received limited attention. Consequently, research has primarily focused on heat-cured composites, for which the benefits of zirconia reinforcement are better established.

This study deals with the comparative evaluation of the effects of locally sourced porcelain particles, untreated zirconia nanoparticles, and yttrium-stabilized zirconia nanoparticle reinforcement fillers on the mechanical and physical properties of reinforced cold-cured PMMA denture composites, which would act as a background for subsequent studies on locally available and conventional reinforcement fillers for PMMA denture composites. Analysis of the mechanical properties (impact strength, Flexural strength, and hardness; including water absorption of cold-cured PMMA denture materials reinforced with 1, 3, 5, and 7 wt. % YSZ-NP was done.

2. MATERIALS AND METHOD

2.1. PMMA Composite Sample Preparation

The sample preparation involved creating a mould using Plaster of Paris (POP) and PYRAX modelling dental wax, followed by investing the formulated reinforcement nanoparticles and PMMA matrix into the mould to fabricate the composite specimens. PYRAX modelling wax was cut into different strips or shapes as required for the mechanical properties' standard dimensions. The characterization table for nano zirconium dioxide and YSZ nanoparticles is shown in Table 1, while the dimensions of the wax are listed below in Table 2.

Table 1: Nano Zirconium Dioxide and YSZ- nanoparticles Characterization Table

Property	Untreated ZrO_2 NP	YSZ- nanoparticles	Test Method
Appearance	White powder	White powder	Visual inspection
Average Particle Size (nm)	80	50 – 60 nm. 91.5% ZrO_2-NP and 5 mol Y_2O_3	Scanning Electron Microscopy
Purity (%)	≥ 99.9	99.9	Inductively Coupled Plasma
Crystal Structure	Monoclinic	Face-centred cubic; tetragonal	X-ray Diffraction
Specific Surface Area (m^2/g)	16	50	Brunauer-Emmett-Teller

Uniform dispersion of reinforcement nanoparticles within the PMMA matrix was critical for achieving consistent reinforcement. This was achieved by mixing the liquid monomer and reinforcement nanoparticles with a magnetic stirrer at 1,500 rpm for approximately 10 minutes to promote uniform dispersion and reduce aggregation. The PMMA powder was gradually added to the nanoparticle-infused monomer. The mixture

was then continuously stirred with a spatula until it reached a dough-like consistency, making it easy to handle. The prepared dough-like composite mixture was then packed into the POP moulds and compressed by a hydraulic press. Care was taken to ensure the material was uniformly packed, filling all cavities and achieving a smooth surface. The filled moulds were left to cure at room temperature for about 20 minutes to ensure complete cold-cure polymerization of the PMMA composite [32]. Once the curing process was complete, the composite specimens were carefully removed from the moulds. The specimens were then trimmed and polished to the required dimensions using fine-grit sandpaper, ensuring they were ready for subsequent testing of their mechanical and physical properties. Figure 2(a) shows the wax cut according to the standard dimensions for mechanical properties tests, while Figure 2(b) shows the unpolished PMMA denture composite materials for mechanical properties characterization.

Figure 2: Images of (a) Modelling wax cut according to the standard dimensions for the mechanical properties to be measured, and (b) Unpolished PMMA denture composite materials for testing.

Table 2: Dimensions of Wax and the Intended Test Property

Dimensions of Wax (mm)	Test Property
65 x 10 x 3 ± 0.03	Flexural Strength
60 x 7 x 4 ± 0.03	Impact Strength
30 x 10 x 3 ± 0.03	Hardness

The raw materials are weighed, and the wax pattern is cut accordingly. The wax pattern is used to generate the mould in the dental flask. The PMMA-nanoparticle mixture is then put inside the mould and allowed to solidify, after which the sample is trimmed. The required amounts of reinforcement nanoparticles (1%, 3%, 5%, and 7% by weight) were accurately weighed using a precision electronic weighing balance. Table 3 shows the percentages and weights of reinforcement nanoparticles and PMMA powders.
The calculation for the reinforcement particles (g) is based on their weight. % is shown in equation (1)

$$\textit{Weight of porcelain/ YSZ} = \left(\frac{\textit{Weight percentage of reinforcement nanoparticles}}{100}\right) \text{x } 20 \qquad (1)$$

Table 3: Percentages and Weights of Reinforcement Nanoparticles and PMMA

Weight Percentage of reinforcement nanoparticles	Weight of PMMA (g)	Weight of reinforcement nanoparticles (g)	Total Weight (g)
0%	20	0	20
1%	19.80	0.2	20
3%	19.40	0.6	20
5%	19.00	1.0	20
7%	18.60	1.4	20

2.2. Mechanical properties testing

The fabricated PMMA composite samples were subjected to mechanical characterization (which includes flexural strength, impact strength, and hardness), including a physical property test - water absorption,

thereby evaluating the effect of 1-7 wt. % of YSZ-NP, Zirconia NP, and porcelain particles reinforcement on the properties of PMMA denture composite materials.

2.3. Impact Strength Testing

The Hounsfield balance Impact machine (bench-mounted Izod Impact Tester, Serial number 3915) with a capacity of 20 Joules, an impact velocity of 11.3 ft. per second, and a 35kg weight was calibrated according to the manufacturer's guidelines. This involved setting the pendulum height to 1 meter, which is specified for standard impact tests. The machine was then adjusted to apply an impact force of 2.5 Joules, as this is the standard for similar materials [33]. Additionally, it was verified that the machine settings were correct for the type of impact test being conducted, ensuring it was properly configured for Izod testing. For the testing procedure, each PMMA composite sample was placed in the impact machine's test chamber, ensuring it was aligned correctly and securely fastened to prevent any movement during the test. The test was then initiated by releasing the pendulum from a height of 1m, applying a single impact with a force of 2.5 J to each sample. The machine recorded the impact strength in Joules, and the values for each PMMA composite sample were documented accordingly. A total of 15 samples were tested.

2.4 Vickers Microhardness Testing

The Vickers microhardness machine (**Matsuzawa MMT-X)** was calibrated according to the manufacturer's guidelines to ensure accurate measurements (ASTM E-384). The machine was set to apply a load of 500 grams-force (gf) for a dwell time of 10 seconds, and measurement resolution of 0.01 **µm** which is standard for testing dental composite materials like PMMA. Each PMMA sample, prepared with varying filler percentages, was carefully placed on the machine's stage, after ensuring that each sample's surface was clean, smooth, and properly positioned under the microscope for precise indentation. The test load was applied by lowering the diamond indenter onto the sample's surface, creating a small indentation. After a 10-second dwell time, the indenter was removed, and the machine's microscope was used to measure the diagonals of the resulting indentation.

Vickers hardness number (HV) was determined utilising the machine's software, which considers the applied load and the diagonal length of the indentation. This process was repeated at different locations on each sample to obtain an average hardness value for the 3 samples tested for each wt. %, making a total of 45 samples. All hardness values were documented for further analysis, with the performance of the various PMMA composite samples with different filler contents compared.

The Vickers micro-hardness number (HV) value was calculated automatically using the equation:

$$HV = 1.8544 \frac{P}{d^2} \quad (2)$$

where; (P) is the applied force in kilograms, (d) is the mean of the two diagonals gained from the indentation in mm.

2.5. Flexural Test

The flexural strength test was performed on PMMA dental composites using an Instron 3366 Universal Testing Machine (UTM). Before testing, the 15 samples for flexural strength test were carefully prepared and checked, ensuring uniformity and the absence of noticeable defects. The samples were placed on the UTM's support spans, with the distance between the supports set according to the standard test requirements. The UTM was configured for a three-point bending test, where a load is applied at the centre of the sample while it is supported at both ends. The test was initiated by applying a gradually increasing load at the midpoint of each sample using the machine's loading head. The tests were done at room temperature using a cross-head speed of 1mm/minute, load capacity of 50 kN and fixture distance of 40 mm. The UTM applied the load at a constant rate until the sample fractured or deformed significantly. During this process, the machine continuously recorded the applied force and the corresponding sample deflection.
Calculation of the flexural strength was done using the formula in Equation (3)

$$Flexural\ Strength\ (\sigma) = \frac{3FL}{2bd^2} \quad (3)$$

Where: ***F*** is the maximum load applied before failure, ***L*** is the support span, ***b*** is the width of the sample, ***d*** is the thickness of the sample.

2.6. Water Absorption Testing Procedure

The water absorption analysis was done in line with (ASTM D1037-98). The PMMA dental composite samples were prepared, to ensure defect-free surfaces. The samples were then dried in a desiccator at 37°C for 24 hours to remove any moisture. After drying, each sample was weighed using a precision analytical balance, and the initial dry weight (W_1) was recorded. The dried samples were immersed in distilled water at 37°C under standard conditions for water-absorption testing. The samples were fully submerged in water for a period of 2 days, with the water temperature maintained consistently throughout the test, then removed, and excess water wiped off from the surfaces using a soft, lint-free cloth. The samples were then immediately weighed again to determine their wet weight (W_2).
The ater absorption was calculated for each sample using Equation (4).

$$Water\ Absorption\ (\%) = \frac{(W_2 - W_1)}{W_1} * 100 \quad (4)$$

Where W_1 is the initial dry weight of the sample, and W_2 is the weight of the sample after immersion.
Data Analysis of results and comparative evaluation of the mechanical properties of Zirconia-, YSZ-, and Porcelain particles reinforced PMMA composites are shown in Tables 4 and 5, respectively.

Table 4: Data Analysis of mechanical properties results (minimum and maximum values)

Property	Minimum value	Maximum value	Mean	Standard deviation	Control value
Hardness (HV)	23.37 (1 wt. % porcelain/PMMA)	37.70 (5 wt. %) YSZ/PMMA)	29.74	4.12	28.27
Flexural strength (MPa)	11.30 (5 wt. % Porcelain/ PMMA)	31.83 (1 wt. % (YSZ/PMMA)	16.99	5.56	19.4
Impact strength (J)	30.72 (1 wt.% Porcelain/PMMA)	33.40 (1 wt. % Zirconia/PMMA)	32.46	0.86	32.27

Table 5: Comparative evaluation of the mechanical properties

Property	Best Material	Value	% vs Control
Hardness	5 wt. % YSZ	37.70 HV	33.40%
Flexural Strength	1 wt. % YSZ	31.83 MPa	64.10%
Impact Strength	1 wt. % ZrO_2	33.40 J	3.50%

3. RESULTS AND DISCUSSION

3.1. Impact strength

The graphical representation of the impact strength (J) obtained from the impact testing conducted on PMMA samples with varying filler contents of YSZ-NP, ZrO_2-NP, and Porcelain particles are shown in Figure 3. The tests were performed using a Hounsfield balanced impact machine calibrated to standard parameters.

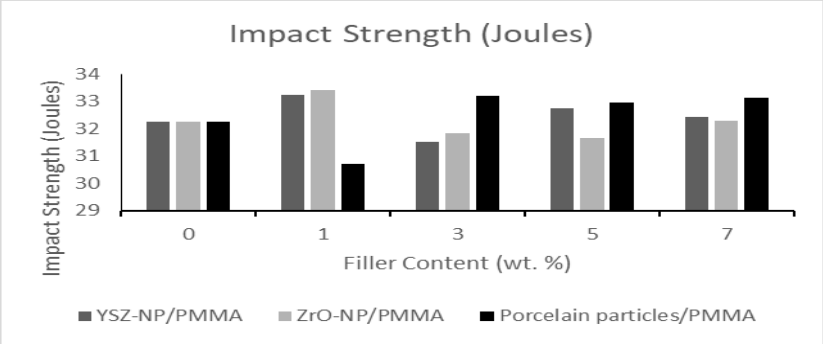

Figure 3: Graphical representation of the Impact Strength (Joules) of PMMA composites with varying filler contents (wt. %).

The maximum impact strength was observed in the 1 wt. % ZrO_2 NP and YSZ-NP reinforced PMMA denture composite samples owing to excellent dispersion of the nanoparticles in the composite material which improved particle-matrix stress transfer within the PMMA composite. On the other hand, as the ZrO_2-NP and YSZ-NP reinforcement used increased in content, the impact strength reduced as observed by Gad et al. [34]**.** Higher nanoparticle concentrations can lead to particle agglomeration, which causes the optimal particle-matrix interaction to diminish, resulting in stress concentration sites that reduce impact strength [9]; [35]. Impact strength reduced at 1 wt. % porcelain particles reinforcement, with subsequent increase from 3-7 wt. % reinforcements when compared to the control sample and other reinforced PMMA composite samples. This can be attributed to excellent dispersion of 3-7 wt. % porcelain fillers with good interfacial adhesion with the PMMA matrix. This implies that the PMMA matrix's toughness increased with the addition of porcelain, thus enhancing the material's resistance to impact as observed in a previous study. [36]

3.2. Vickers Hardness Testing

Graphical representation of the Vickers hardness number (HV) values shown in Figure 4 was obtained by conducting microhardness tests on YSZ-NP, ZrO_2-NP, and Porcelain particles/PMMA composite samples with varying filler percentages.

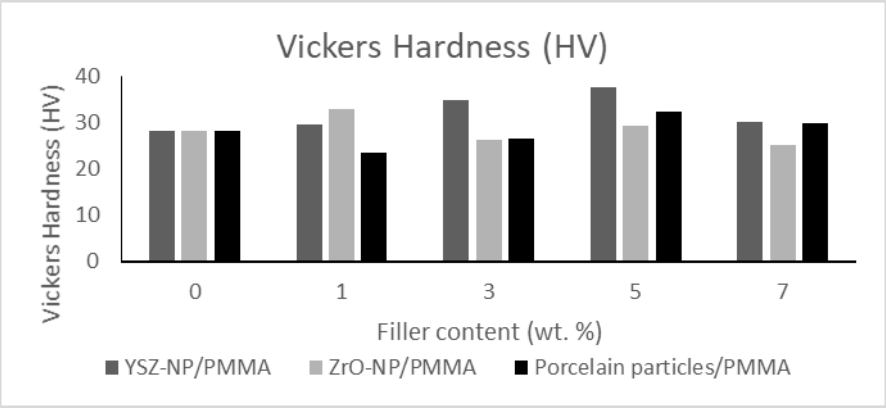

Figure 4: Graphical representation of the Vickers Hardness (HV) of PMMA composites with varying filler contents (wt. %).

YSZ-NP composite samples showed the highest average hardness, compared to other reinforcement fillers, and increased with an increase in filler content (up to 5 wt. %), indicating that the addition of YSZ nanoparticles (YSZ-NP) significantly enhances the hardness of the PMMA matrix. This observation aligns with studies that demonstrate the reinforcement effect of YSZ-NP, which often improves the hardness by acting as barriers to dislocation movement and increasing the stiffness of the composite material [4]**.** YSZ-NP composite sample (7 wt. %), despite having more nanoparticles, showed a lower average hardness than the other wt. % YSZ-NP reinforced PMMA composite samples, but performed better than the control sample. This suggests that excessive nanoparticle content can lead to agglomeration, resulting in stress concentrations and reduced overall mechanical performance [37].

For ZrO_2-NP-reinforced PMMA composites, hardness tests show that PMMA reinforced with zirconia nanoparticles (ZrO_2-NP) exhibits varying hardness values depending on nanoparticle concentration. The highest hardness was observed at 1 wt.% ZrO_2-NP due to optimal nanoparticle dispersion, which improves stress transfer within the PMMA matrix. However, as the concentration increases (3-7 wt.%), the hardness slightly decreases, [38], [39], [40] likely due to nanoparticle agglomeration, which creates stress concentration points rather than uniformly reinforcing the matrix. These findings also align with previous research, which suggests that hardness increases with lower ZrO_2-NP concentrations but may decline at higher levels due to nanoparticle clustering [2]; [37].

3.3. Flexural Strength

Graphical representation of the Flexural Strength (Mpa) of PMMA composites with varying YSZ-NP, ZrO_2-NP, and Porcelain particles reinforcement in weight percentages, is shown in Figure 5.

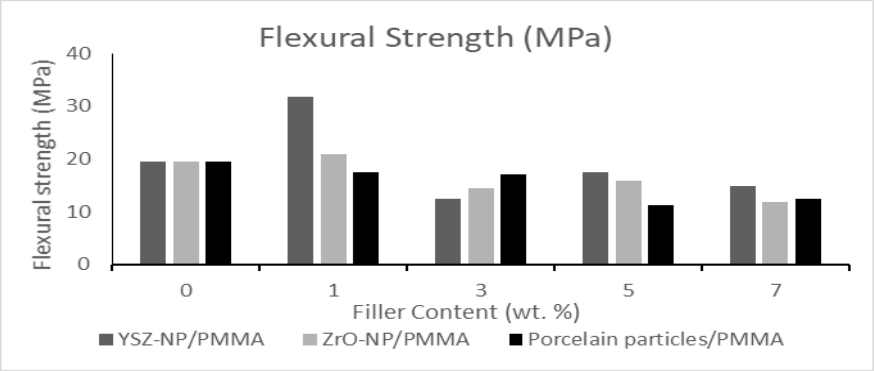

Figure 5: Graphical representation of the Flexural Strength (Mpa) of PMMA composites with varying fillers (wt. %).

At lower filler contents (1 wt. %), the nanoparticles (YSZ-NP, ZrO_2-NP, and Porcelain particles) were better dispersed within the PMMA matrix, leading to a more effective load transfer and an increase in flexural strength. The observed trend aligns with previous studies where the incorporation of lower concentration (1 wt. %) nanoparticles, such as ZrO_2-NP and YSZ-NP, into PMMA matrices enhanced mechanical properties due to improved load transfer at the particle-matrix interface [41], [42], [2], [36]. Though the flexural strength of PMMA composites decreased with the addition of nanoparticles at higher percentages (3-7%), as witnessed in the study by Karci et al [43]. Beyond a certain concentration, nanoparticles' tendency to agglomerate can negatively affect the material's properties, as observed with 3-7 wt.% reinforcements. Although adding zirconia nanoparticles to PMMA would enhance the flexural strength, it can also increase the overall brittleness of the denture at higher reinforcement concentration [5].
With regard to the porcelain particles reinforced PMMA composites, the flexural strength was reduced greatly compared to other fillers. This can be due to the size and dispersion of porcelain particles, which might not be optimal for reinforcement. Larger or unevenly distributed particles could act as stress concentrators, leading to reduced flexural strength [44].

3.4 Water Absorption

The graph in Figure 6 represents the water absorption values obtained from the PMMA composite samples reinforced with (1-7 wt. %) YSZ-NP, ZrO_2-NP, and Porcelain particles after 48 hours of immersion in distilled water at 37°C.

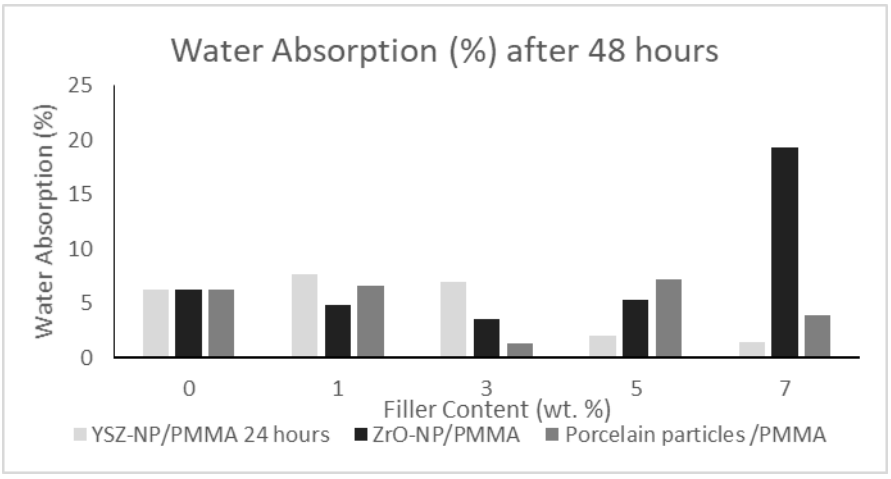

Figure 6: Water absorption (%) for all PMMA composites after 48 Hours

Unreinforced PMMA formulations exhibited water absorption over time, indicating the hydrophilic nature of the acrylic dentures. The reduction in water sorption in YS-zirconia nanoparticle- and porcelain particle-reinforced PMMA may be due to the addition of these nanoparticles to acrylic–resin spaces, which decreased the water-absorbing capacity of the reinforced PMMA denture composites owing to their cross-linking effects. Also, these nanoparticles are considered insoluble, hydrophobic ceramic compounds [45]. The observed trend in water absorption among the PMMA composite samples with varying concentrations of zirconia nanoparticles (ZrO_2-NP) shows that the nanoparticles have the potential to fill voids and microspaces within the PMMA matrix, reducing the overall porosity and thereby limiting the amount of water that can be absorbed [27], [28]. However, this effect is highly dependent on nanoparticle concentration

and dispersion, as at lower concentrations (1 and 3 wt.% ZrO_2-NP), the nanoparticles are likely well-dispersed, effectively reducing water absorption by filling voids in the PMMA matrix. While a significant increase in water absorption was observed in the sample with 7 wt.% ZrO_2-NP after 48 hours suggests possible issues with nanoparticle agglomeration. At higher concentrations, ZrO_2-NPs may tend to agglomerate, creating clusters rather than dispersing uniformly. However, this effect is highly dependent on the nanoparticles' concentration and dispersion. This observation aligns with previous studies that demonstrated similar water-absorption trends in reinforced PMMA composites [27]. YSZ-NP reduced the rate of water absorption with increasing filler content after 48 hours. The higher YSZ nanoparticle concentrations, appear to exhibit lower water absorption compared to the pure PMMA control. This could be attributed to the hydrophobic nature of yttrium-stabilized zirconia nanoparticles and to their good dispersion. Porcelain particles also enhanced the water absorption resistance of the PMMA composite after 48 hours, particularly at 3 and 7 wt. % reinforcement. This could be credited to numerous factors. Firstly, the filler nature of porcelain particles could act as physical barriers, hindering water penetration into the composite. Secondly, porcelain particles interact more readily with the PMMA polymer chains, resulting in a more compact, less permeable structure with enhanced hardness. This observation aligns with previous studies that demonstrated similar water-absorption trends in PMMA/ZrO_2-NP composites. The presence of voids due to nanoparticle agglomeration was cited as a key factor in increased water absorption [46], [21].

4. CONCLUSION

After the comparative evaluation, the best-performing filler overall is Yttrium-Stabilized ZrO_2-NP, which offers enhanced mechanical properties and water-absorption resistance. However, untreated zirconia nanoparticles (NPs) have their own advantages and limitations. Untreated zirconia NPs, particularly at lower concentrations, can exhibit high impact strength, with the highest value of 33.40 J observed at 1 wt.%. This makes them effective against sudden forces, comparable to the best-performing filler. Additionally, untreated zirconia NPs may offer a cost advantage due to less complex processing compared to yttrium-stabilized variants. Nevertheless, untreated zirconia NPs face some drawbacks compared to Yttrium-Treated ZrO_2. For instance, they generally exhibit higher water absorption, with values significantly increasing at higher concentrations. This can lead to concerns about long-term stability and performance in the oral environment. Additionally, untreated zirconia NPs tend to have lower hardness and flexural strength compared to Yttrium-Treated ZrO_2, particularly at higher concentrations.

The results show that YSZ reinforcement considerably enhanced the hardness at 5 wt. %, with 33.4 % increase. Also, a low concentration (1 wt. %) of YSZ gave exceptional flexural strength of 64.1% increase. Impact strength was remarkably stable across all reinforced PMMA composites, with the highest increase of 3.5% observed in 1 wt. % zirconia nanoparticles reinforcement. Porcelain particle reinforcement in general was lower in performance compared to ZrO_2-based formulations, but showed a slight enhancement in mechanical properties compared to the control (100% PMMA denture samples). From the study, the optimal formulation is 1-5 wt.% YSZ-NP which provided the best balance of enhanced hardness (33.4% increase at 5 wt. %), improved flexural strength (64.1% at 1 wt. %), maintained impact strength, and reduced water absorption. It can also be deduced that no single concentration optimizes all properties; thus, trade-offs are required. Porcelain particles and YSZ-NP demonstrated superior water absorption resistance compared to untreated ZrO_2-NP. These findings highlight the potential of porcelain particles, ZrO_2 and YSZ-NP as suitable reinforcements to improve the durability of PMMA dentures in oral environments. *In-vivo* studies can be conducted in the future to assess the performance and durability of these reinforcement fillers in improving the mechanical and physical properties of PMMA denture composites. Hybrid reinforcement using two or more of these fillers, can also be explored.

ACKNOWLEDGEMENT

Research funded by Lagos State Science Research and Innovation Council (LASRIC). UNILAG/LASRIC No.2024/06

REFERENCES

[1] M. Ionescu, A. D. Glodeanu, S. M. Popescu, and I. Roxana, 'A Brief History of Dental Implants', *ISTORIE/HISTORY*, p. 149, 2022.

[2] A. Alhotan, J. Yates, S. Zidan, J. Haider, and N. Silikas, 'Flexural Strength and Hardness of Filler-Reinforced PMMA Targeted for Denture Base Application', *Materials*, vol. 14, no. 10, p. 2659, May 2021, doi: 10.3390/ma14102659.

[3] M. S. Zafar, 'Prosthodontic applications of polymethyl methacrylate (PMMA): An update', *Polymers*, vol. 12, no. 10, p. 2299, 2020.

[4] H. T. Elhmali *et al.*, 'Denture base poly(methyl methacrylate) reinforced with $SrTiO_3$ / Y_2O_3 : Structural, morphological and mechanical analysis', *Polym. Compos.*, vol. 46, no. 10, pp. 8831–8840, Jul. 2025, doi: 10.1002/pc.29523.

[5] S. Zidan, N. Silikas, J. Haider, A. Alhotan, J. Jahantigh, and J. Yates, 'Evaluation of Equivalent Flexural Strength for Complete Removable Dentures Made of Zirconia-Impregnated PMMA Nanocomposites', *Materials*, vol. 13, no. 11, p. 2580, Jun. 2020, doi: 10.3390/ma13112580.

[6] S.-H. Kim and D. C. Watts, 'The effect of reinforcement with woven E-glass fibers on the impact strength of complete dentures fabricated with high-impact acrylic resin', *J. Prosthet. Dent.*, vol. 91, no. 3, pp. 274–280, 2004.

[7] T. Nejatian, N. Nathwani, L. Taylor, and F. Sefat, 'Denture Base Composites: Effect of Surface Modified Nano- and Micro-Particulates on Mechanical Properties of Polymethyl Methacrylate', *Materials*, vol. 13, no. 2, p. 307, Jan. 2020, doi: 10.3390/ma13020307.

[8] A. Yang, D. Zhao, Y. Wu, and C. Xu, 'Effect of polyimide addition on mechanical properties of PMMA-based denture material', *Dent. Mater. J.*, vol. 36, no. 5, pp. 560–565, 2017, doi: 10.4012/dmj.2016-261.

[9] A. Alhotan, J. Yates, S. Zidan, J. Haider, and N. Silikas, 'Assessing Fracture Toughness and Impact Strength of PMMA Reinforced with Nano-Particles and Fibre as Advanced Denture Base Materials', *Materials*, vol. 14, no. 15, p. 4127, Jul. 2021, doi: 10.3390/ma14154127.

[10] M. Yarahmadi *et al.*, 'Micromechanical properties of Yttria-doped zirconia ceramics manufactured by direct ink writing', *J. Eur. Ceram. Soc.*, vol. 43, no. 7, pp. 2884–2893, 2023.

[11] E. L. Medina, J. J. Vaca-González, W. Aperador, S. Ramtani, C. Falentin-Daudre, and D. Garzón-Alvarado, 'Review of Advanced Coatings for Metallic Implants: A Study/Proposal on Yttria-Stabilized Zirconia and Silver-Doped Hydroxyapatite', *JOM*, vol. 77, no. 7, pp. 5345–5361, Jul. 2025, doi: 10.1007/s11837-025-07345-8.

[12] G. A. S. Kazi and R. Yamagiwa, 'Cytotoxicity and biocompatibility of high mol% yttria containing zirconia', *Restor. Dent. Endod.*, vol. 45, no. 4, p. e52, 2020, doi: 10.5395/rde.2020.45.e52.

[13] B. Ali Sabri, M. Satgunam, N. Abreeza, and A. N. Abed, 'A review on enhancements of PMMA Denture Base Material with Different Nano-Fillers', *Cogent Eng.*, vol. 8, no. 1, p. 1875968, Jan. 2021, doi: 10.1080/23311916.2021.1875968.

[14] T. Mishra, P. Mandal, A. K. Rout, and D. Sahoo, 'A state-of-the-art review on potential applications of natural fiber-reinforced polymer composite filled with inorganic nanoparticle', *Compos. Part C Open Access*, vol. 9, p. 100298, 2022.

[15] H. Sharma *et al.*, 'Critical review on advancements on the fiber-reinforced composites: role of fiber/matrix modification on the performance of the fibrous composites', *J. Mater. Res. Technol.*, vol. 26, pp. 2975–3002, 2023.

[16] A. Alhavaz, M. Rezaei Dastjerdi, A. Ghasemi, A. Ghasemi, and A. Alizadeh Sahraei, 'Effect of untreated zirconium oxide nanofiller on the flexural strength and surface hardness of autopolymerized interim fixed restoration resins', *J. Esthet. Restor. Dent.*, vol. 29, no. 4, pp. 264–269, Jul. 2017, doi: 10.1111/jerd.12300.

[17] N. V. Asar, H. Albayrak, T. Korkmaz, and I. Turkyilmaz, 'Influence of various metal oxides on mechanical and physical properties of heat-cured polymethyl methacrylate denture base resins', *J. Adv. Prosthodont.*, vol. 5, no. 3, pp. 241–247, 2013.

[18] E. Kul, L. İ. Aladağ, and R. Yesildal, 'Evaluation of thermal conductivity and flexural strength properties of poly (methyl methacrylate) denture base material reinforced with different fillers', *J. Prosthet. Dent.*, vol. 116, no. 5, pp. 803–810, 2016.

[19] K. Jitwirachot, P. Rungsiyakull, J. A. Holloway, and W. Jia-mahasap, 'Wear Behavior of Different Generations of Zirconia: Present Literature', *Int. J. Dent.*, vol. 2022, no. 1, p. 9341616, Jan. 2022, doi: 10.1155/2022/9341616.

[20] M. Hammed, M. Abbood, and S. M.M, 'Enhancing Dental Ceramic Prostheses with Zirconia Nanocomposites: An In-Vitro Study on Hard Tissue Rehabilitation', *Ann. Chim. - Sci. Matér.*, vol. 48, pp. 137–151, Apr. 2024, doi: 10.18280/acsm.480201.

[21] A. A. Elmadani *et al.*, 'Hybrid denture acrylic composites with nanozirconia and electrospun polystyrene fibers', *PLOS ONE*, vol. 14, no. 12, p. e0226528, Dec. 2019, doi: 10.1371/journal.pone.0226528.

[22] S. C. Ambilkar, T. Singal, and C. Das, 'Diverse role of zirconia in developing polymeric composites', *Polym. Bull.*, vol. 81, no. 8, pp. 6641–6670, 2024.

[23] L. Marchand, V. Fehmer, and I. Sailer, 'Ceramic materials in implant dentistry: an overview', Accessed: Dec. 09, 2025. [Online]. Available: https://blog.iti.org/clinical-insights/ceramic-materials-in-implant-dentistry-an-overview/

[24] M. Mhadhbi, F. Khlissa, and C. Bouzidi, 'Materials for Dentistry', *Adv. Ceram. Mater.*, p. 3, 2021.

[25] P. J. Babu, R. K. Alla, V. R. Alluri, S. R. Datla, and A. Konakanchi, 'Dental ceramics: Part I–An overview of composition, structure and properties', *Am J Mater Eng Technol*, vol. 3, no. 1, pp. 13–8, 2015.

[26] K. J. Anusavice, C. Shen, and H. R. Rawls, *Phillips' science of dental materials*. Elsevier Health Sciences, 2012. Accessed: Dec. 09, 2025. [Online]. Available: https://books.google.com/books?hl=en&lr=&id=gzUeKDhP-KQC&oi=fnd&pg=PP1&dq=Anusavice,+K.+J.,+Shen,+C.,+%26+Ralph,+R.+H.+(2012).+Phillips%E2%80%99+science+of+dental+materials.+Elsevier+Health+Sciences.&ots=BiQ_q6LHkV&sig=dlSNSBPFWmslSIvBTGIu5UQ6-qw

[27] Z. M. A. Monem, Q. A. Hamad, and J. K. Oleiwi, 'DENSITY and water absorption properties of PMMA reinforced by peanut and walnut shells powders used in dental applications', *Iraqi J. Mech. Mater. Eng.*, vol. 21, no. 1, pp. 46–53, 2021.

[28] A. Alhotan, J. Yates, S. Zidan, J. Haider, C. A. Jurado, and N. Silikas, 'Behaviour of PMMA Resin Composites Incorporated with Nanoparticles or Fibre following Prolonged Water Storage', *Nanomaterials*, vol. 11, no. 12, p. 3453, Dec. 2021, doi: 10.3390/nano11123453.

[29] M. Savvilotidou, T. Keller, and A. P. Vassilopoulos, 'Fatigue performance of a cold-curing structural epoxy adhesive subjected to moist environments', *Int. J. Fatigue*, vol. 103, pp. 405–414, 2017.

[30] F. Lionetto, A. Timo, and M. Frigione, 'Cold-cured epoxy-based organic–inorganic hybrid resins containing deep eutectic solvents', *Polymers*, vol. 11, no. 1, p. 14, 2018.

[31] S. R. Kumar, A. Patnaik, and I. K. Bhat, 'Factors influencing mechanical and wear performance of dental composite: a review', *Mater. Werkst.*, vol. 51, no. 1, pp. 96–108, 2020.

[32] N. W. Altaee and A. A. Al -Ali, 'The Effects of Magnesium Oxide Nanoparticles Addition on Flexural Strength of Cold-cured Acrylic Resin material', *Al-Rafidain Dent. J.*, vol. 22, no. 1, pp. 101–112, Mar. 2022, doi: 10.33899/rdenj.2022.129392.1085.

[33] 'ASTM D256 Standard Test Methods For Determining The Izod Pendulum Impact Resistance of Plastics PDF | PDF'. Accessed: Feb. 17, 2026. [Online]. Available: https://www.scribd.com/document/363045569/ASTM-D256-Standard-Test-Methods-for-Determining-the-Izod-Pendulum-Impact-Resistance-of-Plastics-pdf

[34] M. Gad, A. Rahoma, A. M. Al-Thobity, and A. ArRejaie, 'Influence of incorporation of ZrO_2 nanoparticles on the repair strength of polymethyl methacrylate denture bases', *Int. J. Nanomedicine*, vol. Volume 11, pp. 5633–5643, Oct. 2016, doi: 10.2147/IJN.S120054.

[35] R. Lilda G. *et al.*, 'A Comparative Evaluation of The Impact And Flexural Strengths Of High Impact Acrylic Resin Reinforced With Silaned Zirconium Dioxide And Titanium Dioxide Nanoparticles And Its Hybrid Combination - An Invitro Study', *Int. J. Adv. Res.*, vol. 8, no. 02, pp. 781–791, Feb. 2020, doi: 10.21474/IJAR01/10509.

[36] S. Zidan, N. Silikas, A. Alhotan, J. Haider, and J. Yates, 'Investigating the Mechanical Properties of ZrO2-Impregnated PMMA Nanocomposite for Denture-Based Applications', *Materials*, vol. 12, no. 8, p. 1344, Apr. 2019, doi: 10.3390/ma12081344.

[37] A. F. Mohammed, A. M. N. Almohaisen, and K. S. Hassan, 'Mechanical properties of hybrid composites PMMA denture base with varying concentrations of Nano-ZrO2 and glass fiber', *Key Eng. Mater.*, vol. 937, pp. 107–117, 2022.

[38] M. Aboshama, A. Sayed, and A. F. Elhagali, 'Effect of different nano-fillers addition on the mechanical properties of heat-polymerized acrylic resin', *Al-Azhar Assiut Dent. J.*, vol. 5, no. 2, pp. 141–148, 2022.

[39] V. Asopa, S. Suresh, M. Khandelwal, V. Sharma, S. S. Asopa, and L. S. Kaira, 'A comparative evaluation of properties of zirconia reinforced high impact acrylic resin with that of high impact acrylic resin', *Saudi J. Dent. Res.*, vol. 6, no. 2, pp. 146–151, Jul. 2015, doi: 10.1016/j.sjdr.2015.02.003.

[40] N. M. Ayad, M. F. Badawi, and A. A. Fatah, 'Effect of reinforcement of high-impact acrylic resin with zirconia on some physical and mechanical properties', *Arch. Oral Res.*, vol. 4, no. 3, 2008, Accessed: Sep. 30, 2025. [Online]. Available: https://periodicos.pucpr.br/oralresearch/article/view/23218

[41] P. Widodo, W. Mulyawan, N. Djustiana, and I. M. Joni, 'Synthesis and characterization of zirconia–silica PMMA nanocomposite for endodontic implants', *Dent. J.*, vol. 11, no. 3, p. 57, 2023.

[42] D. Barapatre, S. Somkuwar, S. Mishra, and R. Chowdhary, 'The effects of reinforcement with nanoparticles of polyetheretherketone, zirconium oxide and its mixture on flexural strength of PMMA resin', *Eur. Oral Res.*, vol. 56, no. 2, pp. 61–66, 2022.

[43] M. Karci, N. Demir, and S. Yazman, 'Evaluation of Flexural Strength of Different Denture Base Materials Reinforced with Different Nanoparticles', *J. Prosthodont.*, vol. 28, no. 5, pp. 572–579, 2019, doi: 10.1111/jopr.12974.

[44] A. Nabhan, M. Taha, and N. M. Ghazaly, 'Filler loading effect of Al2O3/TiO2 nanoparticles on physical and mechanical characteristics of dental base composite (PMMA)', *Polym. Test.*, vol. 117, p. 107848, 2023.

[45] R. M. Abdelraouf, R. E. Bayoumi, and T. M. Hamdy, 'Influence of Incorporating 5% Weight Titanium Oxide Nanoparticles on Flexural Strength, Micro-Hardness, Surface Roughness and Water Sorption of Dental Self-Cured Acrylic Resin', *Polymers*, vol. 14, no. 18, p. 3767, Jan. 2022, doi: 10.3390/polym14183767.

[46] A. A. Mohammed, 'Evaluation of the properties of poly-Methyl methacrylate reinforced with titanium dioxide for denture application', *J. Eng. Sci. Technol.*, vol. 17, no. 4, pp. 2765–2775, 2022.