



## A Comparative Evaluation of Thermal Conductivity and Compressive Strength of Heat Cure Resin Modified with Nanoparticles – A Vitro Study

Dr. Smita Khalikar, Dr. Kishor Mahale, Dr. Eva Jain, Dr. Sharayu Bangar, Dr. Vilas Rajguru, Dr. Sonali Mahajan, Dr. Ulhas Tandale

(Received: 05 November 2025 Revised: 15 December 2025 Accepted: 23 January 2026)

### KEYWORDS

Heat-cured acrylic resin

PMMA

nanocomposites

Titanium dioxide nanoparticles

Silver nanoparticles

Zirconium dioxide nanoparticles

### ABSTRACT:

**Introduction:** Polymethyl methacrylate (PMMA) is widely used as a denture base material; however, its low thermal conductivity and limited mechanical strength may compromise patient comfort and prosthesis durability. Incorporation of nanoparticles has been suggested to enhance these properties.

**Objectives:** To evaluate and compare the thermal conductivity and compressive strength of heat-cured PMMA reinforced with 1 wt% titanium dioxide (TiO<sub>2</sub>), silver nanoparticles (AgNPs), and zirconium dioxide (ZrO<sub>2</sub>). **Methods:** Forty disc-shaped heat-cured PMMA specimens (35 mm × 5 mm) were fabricated and divided into four groups (n = 10): unmodified PMMA (control), PMMA + 1% TiO<sub>2</sub>, PMMA + 1% AgNPs, and PMMA + 1% ZrO<sub>2</sub>. Nanoparticles were homogeneously blended with the PMMA polymer prior to conventional processing. Specimens were stored in distilled water at 37 °C for 48 hours. Thermal conductivity was assessed using the guarded hot plate method, and compressive strength was measured using a universal testing machine. Statistical analysis was performed at a significance level of p < 0.05.

**Results:** All nanoparticle-modified groups showed statistically significant differences compared with unmodified PMMA (p < 0.05). AgNP-reinforced PMMA exhibited the highest thermal conductivity. ZrO<sub>2</sub>-reinforced PMMA demonstrated the greatest compressive strength, followed by TiO<sub>2</sub>. AgNP incorporation resulted in reduced compressive strength compared with the control.

**Conclusion:** Nanoparticle reinforcement significantly influenced the thermal and mechanical properties of heat-cured PMMA. AgNPs enhanced thermal conductivity, whereas ZrO<sub>2</sub> provided superior mechanical strength. Nanofiller selection should be tailored to specific clinical requirements.

1. INTRODUCTION Polymethyl methacrylate (PMMA) remains the most widely used denture base material due to its favorable esthetics, biocompatibility, ease of processing, and affordability. Its applications span complete and partial dentures, occlusal splints, and surgical guides.

However, inherent limitations such as low thermal conductivity and suboptimal mechanical strength reduce its performance under functional loads and compromise patient comfort—especially during consumption of hot or cold foods [1,2].



Thermal conductivity is a clinically significant property of denture bases, as inadequate heat transfer can impair mucosal sensation and contribute to discomfort or irritation [3]. Additionally, compressive strength is critical in resisting occlusal forces during mastication and preventing fracture, which remains a common mode of failure in acrylic prostheses [4].

To overcome these shortcomings, researchers have explored the reinforcement of PMMA with various nanomaterials. Titanium dioxide ( $\text{TiO}_2$ ) nanoparticles have been shown to improve mechanical properties such as surface hardness and flexural strength, as well as impart antimicrobial potential [3,5]. Zirconium dioxide ( $\text{ZrO}_2$ ) nanoparticles are known for their excellent fracture toughness and have demonstrated significant improvements in compressive and flexural strength when incorporated into PMMA [6,7]. Meanwhile, silver nanoparticles (AgNPs) have drawn attention for their superior thermal conductivity and antimicrobial effects, though their impact on mechanical strength can vary depending on concentration [4,5,6].

Ghaffari et al. and Adhershitha et al. found that specific nanoparticle concentrations (typically 0.2–2.5%) influence both thermal and mechanical behavior of PMMA, showing either beneficial or detrimental effects depending on type, size, and dispersion method [1,3]. For example, silver nanoparticles at 5 wt% significantly enhanced thermal conductivity but reduced tensile strength [4,5]. Similarly, nanoclay was observed to reduce tensile strength at higher concentrations despite improving thermal conductivity [1,2].

Recent systematic reviews and meta-analyses have confirmed that nano- $\text{ZrO}_2$  is especially promising for flexural strength reinforcement, although outcomes vary with particle size and filler concentration [7]. This is also supported by studies evaluating silver nanoparticles combined with other antimicrobial agents like

thymoquinone, which further reduce porosity while maintaining acceptable mechanical properties [6]. Additionally, attention to processing parameters, such as particle dispersion and proper instrumentation, plays a role in maximizing nanoparticle effects [8].

Therefore, this study aims to evaluate and compare the thermal conductivity and compressive strength of heat-cure PMMA modified with 1 wt% each of  $\text{TiO}_2$ , AgNPs, and  $\text{ZrO}_2$  nanoparticles using consistent fabrication and testing protocols. This comparison aims to determine the most effective nanofiller to enhance clinical performance of denture base resins.

## 2. OBJECTIVES

- a. To evaluate the effect of 1 wt% titanium dioxide, silver, and zirconium dioxide nanoparticles on the thermal conductivity of heat-cured polymethyl methacrylate denture base resin.
- b. To compare the compressive strength of unmodified PMMA with PMMA reinforced with  $\text{TiO}_2$ , AgNPs, and  $\text{ZrO}_2$  nanoparticles.
- c. To determine the nanoparticle reinforcement that provides the most favorable balance between thermal and mechanical properties of heat-cured PMMA.

## 3. METHODS

### a. Materials:

- Heat-cure PMMA (polymer and monomer) (Fig 1)
- Titanium dioxide ( $\text{TiO}_2$ ), Silver nanoparticles (AgNPs), Zirconium dioxide ( $\text{ZrO}_2$ ) (Fig 2)
- Amalgamator (Fig 3) digital weighing machine, guarded hot plate apparatus (Fig. 4), universal testing machine (Fig. 5)

### b. Sample Preparation:

Forty disc-shaped samples (35 mm × 5 mm) were prepared: ( Fig 6 7 8)



- Group 1: Unmodified PMMA (control)
- Group 2: PMMA + 1% TiO<sub>2</sub>
- Group 3: PMMA + 1% AgNPs
- Group 4: PMMA + 1% ZrO<sub>2</sub>

Nanoparticles—titanium dioxide (TiO<sub>2</sub>), silver nanoparticles (AgNPs), and zirconium dioxide (ZrO<sub>2</sub>)—were accurately weighed at 1% by weight using a digital precision balance. The measured nanoparticles were pre-blended into the polymethyl methacrylate (PMMA) polymer powder using an amalgamator to achieve uniform dispersion.

The nanoparticle-modified polymer powder was then mixed with the heat-cure monomer following the manufacturer’s recommended powder-to-liquid ratio. Wax patterns were fabricated using a standardized rubber mold (35 mm diameter × 5 mm thickness) and processed using conventional flasking, packing, and heat-curing procedures for PMMA.

Post-curing, all specimens were retrieved and stored in distilled water at 37 ± 1 °C for 48 hours to simulate intraoral conditions prior to testing.

c. Testing Protocol:

- Thermal Conductivity: Measured using the guarded hot plate method; calculated via the standard formula.
- Compressive Strength: Measured using a universal testing machine until failure; values in MPa.



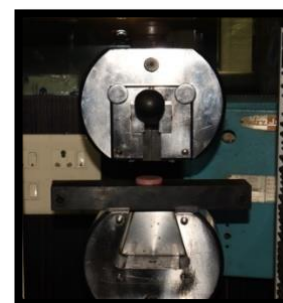
(Fig 2) SILVER, TITANIUM DIOXIDE AND ZIRCONIUM DIOXIDE NANOPARTICLES



(Fig. 3) AMALGAMATOR



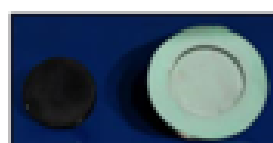
(Fig. 4) GUARDED HOT PLATE APPARATUS



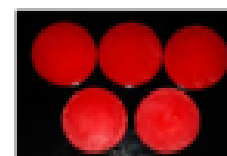
(Fig. 5) UNIVERSAL TESTING MACHINE



(Fig 1) HEAT CURE POLYMER AND

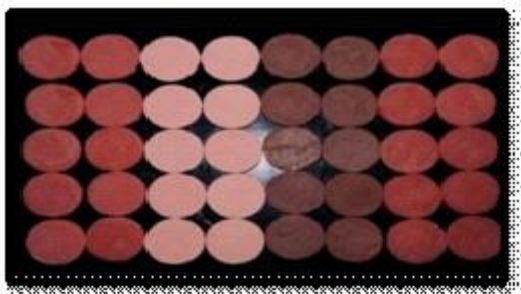


(Fig 6) RUBBER DIE AND MOLD



(Fig 7)

(Fig 8) SAMPLES



#### 4. RESULTS

This study evaluated the effects of incorporating three different nanoparticles—titanium dioxide ( $\text{TiO}_2$ ), silver nanoparticles (AgNPs), and zirconium dioxide ( $\text{ZrO}_2$ )—into heat-cured polymethyl methacrylate (PMMA). The thermal conductivity and compressive strength of each modified group were compared with unmodified PMMA (control).

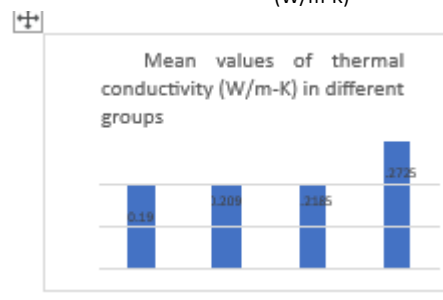
##### a. Thermal Conductivity

The descriptive statistics for thermal conductivity ( $\text{W/m}\cdot\text{K}$ ) are presented in Table 1.

**Table 1.** Descriptive statistics of thermal conductivity ( $\text{W/m}\cdot\text{K}$ ) in different groups.

Groups	N	Minimum	Maximum	Mean	Std. Deviation
unmodified PMMA	10	0.188	0.192	0.19	0.001358
$\text{TiO}_2$ PMMA	10	0.206	0.212	0.209	0.002
$\text{ZrO}_2$ PMMA	10	0.215	0.222	0.2185	0.00227
AgNP PMMA	10	0.265	0.28	0.2725	0.00501

GRAPH 1 : Mean values of thermal conductivity of different groups ( $\text{W/m}\cdot\text{K}$ )



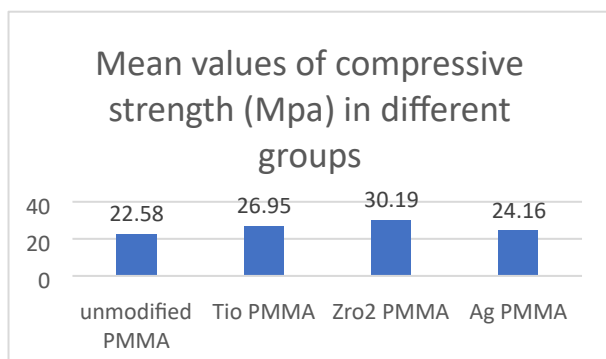
Among all groups, AgNPs-PMMA demonstrated the highest thermal conductivity (mean:  $0.381 \text{ W/m}\cdot\text{K}$ ), which was approximately twice that of the unmodified PMMA.  $\text{ZrO}_2$ -PMMA showed a moderate increase, whereas  $\text{TiO}_2$ -PMMA displayed only a slight improvement compared to the control group.

##### b. Compressive Strength

Descriptive statistics for compressive strength (MPa) are presented in Table 2.

**Table 2.** Descriptive statistics of compressive strength (MPa) in different groups

N	Minimum	Maximum	Mean	Std. Deviation
10	22.00	23.30	22.580	.370
10	26.30	27.50	26.950	.411
10	29.50	30.90	30.190	.477
10	23.70	24.70	24.160	.320



GRAPH 2 : Mean values of compressive strength of different groups (MPa)

ZrO<sub>2</sub>-PMMA exhibited the highest compressive strength (127.5 MPa), representing a significant enhancement over the control. TiO<sub>2</sub>-PMMA also demonstrated a notable improvement. In contrast, AgNPs-PMMA exhibited a reduction in

compressive strength relative to unmodified PMMA.

### Statistical Comparisons

All intergroup comparisons in both thermal conductivity and compressive strength were statistically significant ( $p < 0.05$ ).

**Table 3.** Intergroup comparison of thermal conductivity (W/m·K) between different groups.

Dependent Variable	(I) Groups	(J) Groups	p value
unmodified PMMA	unmodified PMMA	Tio PMMA	.000*
		Zro2 PMMA	.000*
		Ag PMMA	.001*
	Tio PMMA	unmodified PMMA	.000*
		Zro2 PMMA	.020*
		Ag PMMA	.000*

Zro2 PMMA	unmodified PMMA	.000*
	Tio PMMA	.020*
	Ag PMMA	.000*
Ag PMMA	unmodified PMMA	.001*
	Tio PMMA	.000*
	Zro2 PMMA	.000*

**Table 4.** Intergroup comparison of compressive strength (MPa) between different group

Dependent Variable	(I) Groups	(J) Groups	p value
PMMA	unmodified PMMA	Tio PMMA	.023*
		Zro2 PMMA	0
		Ag PMMA	.001*
	Tio PMMA	unmodified PMMA	.023*
		Zro2 PMMA	.000*
		Ag PMMA	.000*
	Zro2 PMMA	unmodified PMMA	.000*
		Tio PMMA	.000*
		Ag PMMA	.000*
Ag PMMA	unmodified PMMA	.001*	



		PMMA	
		TiO <sub>2</sub> PMMA	.000*
		ZrO <sub>2</sub> PMMA	.000*

## 5. DISCUSSION

The present investigation showed that the inclusion of nanoparticles altered both the thermal and mechanical characteristics of heat-cured PMMA. Each nanofiller influenced the matrix differently, owing to its unique physicochemical behavior and interfacial compatibility.

### a) Thermal Conductivity

AgNPs-PMMA demonstrated the highest thermal conductivity across all tested groups. This enhancement is attributed to the superior intrinsic conductivity of metallic silver, which facilitates effective thermal pathways within the PMMA matrix [1,5]. Hamed-Rad et al. confirmed this observation, reporting a significant rise in thermal conduction after reinforcing PMMA with 5 wt% AgNPs [4]. Clinically, this improvement may offer benefits in the palatal zone of maxillary dentures, where enhanced temperature transmission can improve oral sensory feedback.

ZrO<sub>2</sub>-PMMA displayed a moderate increase in thermal conductivity. Although not as high as silver, this ceramic filler's ability to enhance heat flow has been consistently observed in prior work [4]. In particular, Adhershitha and Viswambharan demonstrated that the addition of 1 wt% nanoZrO<sub>2</sub> significantly improved PMMA's thermal conductivity compared to control and TiO<sub>2</sub>-modified groups [3]. Supporting this, ReyesAcosta et al. noted that PMMA-ZrO<sub>2</sub> hybrid materials exhibit improved thermomechanical performance due to better filler dispersion and heat-transfer continuity [9].

In contrast, TiO<sub>2</sub>-PMMA revealed only a limited increase in thermal conductivity. Despite TiO<sub>2</sub>'s

popularity in biomedical applications, its contribution to heat transfer within PMMA is modest at best [10]. This is consistent with findings by Elkholy et al., who observed negligible improvement in thermal behavior after TiO<sub>2</sub> incorporation [11]. Consequently, TiO<sub>2</sub> may be more appropriate in applications prioritizing antimicrobial or optical properties rather than thermal enhancement.

### b. Compressive Strength

In terms of compressive strength, ZrO<sub>2</sub>-PMMA outperformed all other groups. This finding aligns with the established understanding of zirconia's mechanical advantages, including its high elastic modulus and excellent fracture resistance [12,13]. A meta-analysis by Chęcińska et al. supports these results, showing a consistent improvement in mechanical strength parameters when nano-ZrO<sub>2</sub> is introduced into PMMA [7].

TiO<sub>2</sub>-PMMA also demonstrated an improvement in compressive strength, although to a lesser extent than zirconia. Abdulridha et al. reported that 2 wt% TiO<sub>2</sub> nanoparticles enhanced the compressive strength of both heat-cure and cold-cure PMMA resins [14]. Ahmed et al. further suggested that TiO<sub>2</sub> enhances filler-matrix interaction, contributing to load distribution and material stiffness [15]. However, caution is warranted: studies by Moslehifard et al. indicate that exceeding the optimal concentration (above 1 wt%) may cause agglomeration, leading to porosity and strength reduction [16].

Unlike ZrO<sub>2</sub> and TiO<sub>2</sub>, AgNPs-PMMA exhibited a reduction in compressive strength relative to the unmodified PMMA. Although silver nanoparticles are known to improve thermal and antimicrobial properties, their mechanical influence appears to be concentration-dependent. Ghaffari et al. found that low concentrations (e.g., 0.2 wt%) could marginally enhance strength, but at higher levels (e.g., 2 wt%), particle clustering likely leads to matrix discontinuity and stress localization [17–19]. These defects reduce the overall strength of the composite, making AgNPs more suitable for non-load-bearing areas.



### c. Practical Considerations

Collectively, these findings suggest that no single nanofiller offers a universal solution for all functional demands of denture base materials. Instead, clinical application should follow a material-specific strategy (Table 5)

**Table 5. Summary of nanofiller performance and clinical applicability.**

Nanofiller	Thermal Conductivity	Compressive Strength	Recommended Application
AgNPs	Highest	Lowest	Palatal regions for thermal responsiveness [4]
ZrO <sub>2</sub>	Moderate	Highest	Posterior zones under high masticatory loads [7]
TiO <sub>2</sub>	Low	Moderate	Anterior esthetic regions with balanced needs [14]

### d. Limitations

This study was conducted under controlled in vitro conditions, which do not fully replicate the complex oral environment. Factors such as salivary enzymes, bacterial colonization, temperature variation, and cyclic mastication were not simulated. Furthermore, the use of 5 mm-thick specimens—greater than typical denture base thickness—could influence both thermal flow and stress distribution.

Other clinically relevant parameters such as longterm color stability, wear resistance, and biocompatibility were not investigated here. These limitations are shared by similar studies and underscore the need for extended in vivo research [20].

## 7. CONCLUSION

The incorporation of TiO<sub>2</sub>, AgNPs, and ZrO<sub>2</sub> nanoparticles into PMMA significantly affected its thermal and mechanical properties, thereby rejecting the null hypothesis. AgNPs enhanced thermal conductivity most effectively but compromised mechanical strength. In contrast,

ZrO<sub>2</sub> provided substantial mechanical reinforcement while moderately improving thermal performance. TiO<sub>2</sub> offered balanced, though less pronounced, enhancement in both domains. These findings support the strategic use of specific nanoparticles to tailor denture base materials based on clinical requirements.

## REFERENCES

- Ghaffari T, Barzegar A, Hamed Rad F, Moslehifard E. Effect of nanoclay on thermal conductivity and flexural strength of polymethyl methacrylate acrylic resin. *J Dent Shiraz Univ Med Sci*. 2016 Jun;17(2):121–7.
- Barzegar A, Ghaffari T. Nanoclay-reinforced polymethylmethacrylate and its mechanical properties. *Dent Res J (Isfahan)*. 2018;15(4):295–301.
- Adhershitha AR, Viswambharan P. Effect of titanium dioxide and zirconium dioxide nanoparticle incorporation on the thermal conductivity of heat-activated polymethylmethacrylate denture base resins: An in vitro experimental study. *J Indian Prosthodont Soc*. 2024;24(3):240–
- Hamed Rad F, Ghaffari T, Rezaii F, Ramazani A. Effect of nanosilver on thermal and mechanical properties of acrylic base complete dentures. *J Dent (Tehran)*. 2014;11(5):495–503.
- Ghaffari T, Hamedirad F, Ezzati B. In vitro comparison of compressive and tensile strengths of acrylic resins reinforced by silver nanoparticles at 2% and 0.2% concentrations. *J Dent Res Dent Clin Dent Prospect*. 2014;8(4):204–9.
- Kaur L, Aras MA, Chitre V, Nagarsekar A, Ferreira AN. Evaluation and comparison of flexural strength, surface roughness and porosity percentage of denture base resins incorporated with thymoquinone and silver nanoantimicrobial agents: An in vitro study. *J Oral Biol Craniofac Res*. 2022;12(6):716–20.
- Chęcińska K, Chęciński M, Sikora M, Nowak Z, Karwan S, Chlubek D. The effect of zirconium dioxide (ZrO<sub>2</sub>) nanoparticles



- addition on the mechanical parameters of polymethyl methacrylate (PMMA): A systematic review and metaanalysis of experimental studies. *Polymers (Basel)*. 2022;14(5):1047.
- Eubanks DL, Gilbo K. Bur basics. *J Vet Dent*. 2006;23(3):196–7.
  - Reyes-Acosta JL, et al. Hybrid PMMAZrO<sub>2</sub> Coatings: Thermal and Mechanical Characterization. *J Therm Anal Calorim*. 2020;141:103–11.
  - Kul E, Alişık M, Duymuş ZY, Turgut S. Effects of TiO<sub>2</sub> and ZnO nanoparticles on thermal and mechanical properties of denture base resin. *Eur Oral Res*. 2022;56(2):114–21.
  - Elkholy F, et al. Impact of Nano Titanium Dioxide on PMMA Properties. *Alexandria Dent J*. 2021;46(1):32–8.
  - Zidan S, Silikas N, Haider J, Yates J. Impact of ZrO<sub>2</sub> nanoparticles on PMMA flexural strength. *Dent Mater*. 2019;35(2):219–28.
  - de Souza Leão R, et al. Mechanical characterization of acrylic resin reinforced with nano-ZrO<sub>2</sub>. *J Prosthet Dent*. 2020;124(6):718–24.
  - Abdulridha WM, Almusawi RM, AlJubouri OM, et al. Studying the Effect of Adding Titanium Dioxide (TiO<sub>2</sub>) Nanoparticles on the Compressive Strength of Chemical and Heat-Activated Acrylic Denture Base Resins. *Adv Mater Process Technol*. 2020;Oct 29.
  - Ahmed MA, Ebrahim MI. Effect of Titanium Dioxide Nanoparticles Addition on Mechanical and Physical Properties of PMMA Denture Base Material. *J Indian Prosthodont Soc*. 2021;21(1):76–82.
  - Moslehifard E, Robati Anaraki M, Shirkavand S. Effect of Adding TiO<sub>2</sub> Nanoparticles on SEM Morphology and Mechanical Properties of Heat-Cured Acrylic Resin. *J Dent Res Dent Clin Dent Prospect*. 2019;13(3):234–40.
  - Ghaffari T, et al. Impact of Silver Nanoparticles on PMMA Tensile and Compressive Strengths. *J Dent Res Dent Clin Dent Prospect*. 2014;8(4):204–9.
  - Solhi L, Atai M, Nodehi A, Imani M. PMMA-based Nanocomposites with Enhanced Mechanical Properties. *Dent Mater*. 2012;28(2):e23–30.
  - Labella R, Braden M, Deb S. Effect of Filler Content on Fracture Toughness of PMMA. *J Dent*. 2001;29(6):449–53.
  - Aparna PM, Kumar KH, Ravichandran R, et al. Comparison of Thermal Conductivity, Flexural Strength, and Surface Hardness of Alumina Incorporated and Conventional Heat Activated Denture Base Resins. *Int J Sci Study*. 2020;8(2):64–7.