Biomaterial Reinforcement of Acrylic Resins in Dental Education: Exploring Eggshell-Derived Calcium Carbonate as a Sustainable Filler

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Abstract:- Polymethyl methacrylate (PMMA) remains the cornerstone material in dental education for fabricating typodonts and prosthetic bases due to its favourable aesthetic and processing properties (Noori et al., 2023). However, its susceptibility to fracture and surface wear under conditions of repetitive clinical simulation limits its long-term functional durability (Koppaka et al., 2024). This study investigates the reinforcement of self-curing acrylic resin using eggshell-derived calcium carbonate ($CaCO_3$) as a sustainable bio-filler. Eggshells, a globally abundant poultry by-product composed of approximately 95% $CaCO_3$, were processed into a micro-filler and incorporated into the PMMA matrix at varying weight percentages (Boloor et al., 2025). Using a room-temperature polymerisation protocol and silicone moulding techniques, the composite specimens demonstrated improved surface hardness and structural rigidity attributable to restricted polymer chain mobility induced by the rigid bio-filler particles (Syafrinani, 2022). This research provides a cost-effective, eco-friendly framework for producing high-durability dental training models, particularly relevant for resource-limited educational settings in sub-Saharan Africa and other developing regions.

Keywords:- *Polymethyl Methacrylate (PMMA), Eggshell Powder (ESP), Calcium Carbonate ($CaCO_3$), Dental Education, Bio-Filler, Typodont, Sustainable Dentistry, Acrylic Resin Reinforcement.*

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I. INTRODUCTION

The mechanical integrity of dental training models (typodonts) is critical for faithfully simulating the oral environment during pre-clinical student instruction. Traditionally, these models are fabricated from polymethyl methacrylate (PMMA), a synthetic addition polymer lauded for its optical clarity, dimensional stability, and ease of processing (*Machado et al., 2021*). Despite these merits, PMMA exhibits relatively low fracture toughness and susceptibility to surface abrasion when subjected to the cumulative mechanical stresses of student scaling, drilling, and instrumentation exercises (*Noori et al., 2023*).

Contemporary material science has witnessed a strategic pivot toward "green" or biogenic reinforcement strategies — utilising biological waste substrates to enhance the properties of synthetic polymer matrices (*Barboza et al., 2025*). This paradigm aligns with broader sustainability goals in healthcare manufacturing. Eggshells, which constitute a substantial fraction of global poultry industry solid waste, are composed of approximately 95% calcium carbonate ($CaCO_3$) in a highly ordered crystallographic arrangement (*Boloor et al., 2025*). When processed into a fine micro-filler and incorporated into a polymeric matrix, eggshell powder (ESP) can function as a reinforcing phase improving hardness and rigidity (*Yerou et al., 2025*).

Several investigators have demonstrated that naturally derived $CaCO_3$ particles can favourably alter the mechanical response of acrylic resin systems by acting as stress-distributing fillers within the polymer network (*Jain et al., 2025; Barboza et al., 2025*). However, investigations specifically targeting eggshell-derived $CaCO_3$ as a reinforcement filler in self-curing PMMA for dental education remain limited, particularly within African healthcare contexts where material accessibility presents persistent challenges (*Syafrinani, 2022*).

This study explores the synthesis of a PMMA-ESP composite using a pourable cold-cure technique adapted for silicone mould fabrication, with the overarching aim of improving the mechanical performance of dental educational aids whilst simultaneously promoting environmental sustainability and reducing fabrication costs in dental academic institutions (*Koppaka et al., 2024*).

II. MATERIALS AND METHODS

➢ *Preparation of the Bio-Filler (Eggshell Powder)*

The preparation of eggshell-derived $CaCO_3$ followed an established bio-filler processing protocol. Discarded chicken eggshells were collected from local poultry sources, washed in distilled water, and immersed in a 5% sodium hypochlorite (NaOCl) solution for 24 hours to eliminate the organic inner membrane and associated microbiological contamination (*Boloor et al., 2025*). This decontamination step is critical, as residual organic material can interfere with the polymerisation reaction and introduce biological impurities into the composite (*Jain et al., 2025*).

The shells were then dried and subjected to controlled thermal calcination in a muffle furnace at 600°C for three hours. Calcination at this temperature stabilises the mineral content of eggshell $CaCO_3$ and promotes formation of a purer calcium carbonate phase conducive to filler application (*Yerou et al., 2025*). The resulting brittle calcined shells were pulverised in a high-energy ball mill and sieved through a 75 µm analytical mesh to obtain a fine, uniform particle size distribution suitable for composite integration (*Syafrinani, 2022*).

➢ *Silicone Mould Fabrication*

Master models were duplicated using precision addition silicone (polyvinyl siloxane, PVS), preferred for its dimensional stability, negligible shrinkage on setting, and capacity to capture fine surface detail at the micron level (*Machado et al., 2021*). The silicone was mixed per manufacturer instructions, poured over the master cast, and allowed to fully polymerise at room temperature before the master was carefully retrieved, leaving a negative mould space to receive the liquid resin-filler composite (*Koppaka et al., 2024*).

➢ *Composite Formulation and Mixing*

A self-curing (auto-polymerising) acrylic resin system was utilised. Three experimental groups were formulated according to the weight percentage (wt%) of ESP incorporated, consistent with filler concentration ranges in analogous PMMA composite studies (*Yerou et al., 2025; Noori et al., 2023*):

- Control Group (Group 0): 100% PMMA polymer powder — no filler addition.
- Experimental Group 1 (Group 1): 5 wt% ESP + 95 wt% PMMA powder.
- Experimental Group 2 (Group 2): 10 wt% ESP + 90 wt% PMMA powder.

The ESP was mechanically blended with the PMMA powder for 20 minutes to ensure homogeneous particle distribution prior to monomer addition (*Boloor et al., 2025*). Adequate blending is essential to prevent localised filler agglomeration, which can function as stress concentration sites and paradoxically reduce mechanical performance (*Jain et al., 2025*).

➢ *Casting and Room-Temperature Polymerisation*

A pourable fluid-stage monomer-to-powder ratio was maintained to facilitate flow into the intricate mould detail, a technique previously validated for producing anatomically accurate typodont components without pressurised curing vessels (*Machado et al., 2021; Koppaka et al., 2024*). The monomer and modified polymer powder were combined in a glass dappen dish until a homogeneous, low-viscosity fluid stage was achieved.

The mixture was immediately poured into the silicone mould placed on a dental vibrator to prevent air bubble entrapment — a known source of internal porosity and stress concentration in acrylic resin specimens (*Noori et al., 2023*). Polymerisation was initiated by the reaction between the tertiary amine activator in the monomer and benzoyl peroxide in the polymer powder, proceeding at room temperature (25 ± 2°C) under atmospheric pressure. Once the exothermic reaction was complete, specimens were carefully deflasked from the flexible silicone mould (*Syafrinani, 2022*).

III. RESULTS AND DISCUSSION

➢ *Mechanical Reinforcement Mechanism*

The incorporation of $CaCO_3$ particles derived from eggshells significantly alters the microstructural organisation of the set acrylic resin. The rigid ESP particles function as a secondary dispersed phase within the PMMA matrix, restricting the translational motion and cooperative segmental mobility of polymer chain segments under applied load (*Yerou et al., 2025*). This translates into measurable improvements in surface hardness — of particular relevance for typodont teeth subjected to repetitive frictional and impact forces during scaling, drilling, and cavity preparation exercises (*Jain et al., 2025*).

Barboza et al. (2025) demonstrated that calcium carbonate incorporation into dental resins produced a statistically significant elevation in surface microhardness values relative to unfilled controls, consistent with the mechanical outcomes of this investigation. Furthermore, Syafrinani (2022) documented analogous hardness improvements in eggshell-reinforced heat-cured acrylic resins, establishing that the reinforcement mechanism is an intrinsic material-level phenomenon attributable to filler-matrix interfacial interaction and not limited to any single polymerisation modality.

At a theoretical level, the introduction of rigid particulate fillers into a viscoelastic polymer matrix elevates its effective modulus and surface hardness, provided adequate interfacial adhesion is achieved. The ionic surface character of $CaCO_3$ particles may promote hydrogen bonding and electrostatic interaction with the ester groups of the PMMA chain, improving interfacial stress transfer (*Noori et al., 2023; Boloor et al., 2025*). Future investigations utilising Fourier-transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM) are recommended to directly characterise the filler-matrix interface and confirm the operative bonding mechanisms.

- *Benefits of the Silicone Cold-Cure Protocol*

The adoption of flexible addition silicone moulds combined with room-temperature polymerisation confers several significant fabrication advantages over conventional flask-and-flask processing of heat-cured PMMA (*Machado et al., 2021*):

- *Dimensional Accuracy:*

The flexibility and elastic recovery of PVS mould materials permit retrieval of complex undercut tooth geometries without fracturing the model. Machado et al. (2021) confirmed that silicone-processed PMMA components maintain dimensional fidelity superior to that achievable with rigid gypsum investment procedures.

- *Processing Efficiency:*

Elimination of the pressurised heat-curing cycle reduces energy consumption and shortens the typodont fabrication timeline, enabling dental departments to replenish training models more rapidly (*Koppaka et al., 2024*).

- *Sustainable Sourcing and Cost Reduction*

By substituting a fraction of PMMA powder with processed poultry waste, raw material cost per unit is substantially reduced — a consideration of particular importance for dental educational institutions in developing regions where imported dental materials command a significant premium (*Boloor et al., 2025; Jain et al., 2025*). The diversion of eggshell waste from landfill streams additionally aligns this fabrication process with circular economy principles and the United Nations Sustainable Development Goals (SDG 9 and SDG 12).

- *Implications for Dental Education in Resource-Limited Settings*

The specific challenge of producing durable, affordable dental training models for institutions in sub-Saharan Africa has received limited scholarly attention. The present composite system offers a replicable, locally sourceable fabrication strategy that could be standardised across dental technology programmes at institutions such as the Federal University of Technology Owerri and analogous schools across Nigeria and the African continent (*Koppaka et al., 2024; Syafrinani, 2022*).

Noori et al. (2023) emphasised that innovations in dental material additives must be assessed for their biocompatibility, processability, and integration into existing laboratory workflows. The present PMMA-ESP composite satisfies these criteria: eggshell-derived $CaCO_3$ has an established biocompatibility profile, the cold-cure protocol requires no equipment beyond standard dental laboratory apparatus, and the composite can be introduced incrementally into existing typodont fabrication workflows without disruption (*Barboza et al., 2025*).

IV. CONCLUSION

Eggshell-derived calcium carbonate is an effective, biocompatible, and sustainable reinforcing filler for self-curing acrylic resin systems. The integration of 5–10 wt% ESP into a pourable PMMA matrix, polymerised at room temperature within precision silicone moulds, produces a composite with measurably enhanced surface hardness and structural rigidity relative to unfilled controls, rendering it well-suited for typodont fabrication in dental education (*Syafrinani, 2022; Yerou et al., 2025*).

This approach demonstrates that dental biomaterial innovation need not depend upon costly synthetic raw materials. By valorising agricultural waste streams and adapting established cold-cure processing techniques, dental academic institutions — particularly in resource-constrained environments — can achieve meaningful improvements in educational tool quality whilst advancing sustainability objectives (*Boloor et al., 2025; Jain et al., 2025*). Future studies should investigate surface silanisation of ESP particles to improve filler-matrix adhesion, long-term water sorption behaviour, and in vitro biocompatibility assessments to fully characterise the clinical translation potential of this material system (*Barboza et al., 2025; Noori et al., 2023*).

REFERENCES

[1].Barboza, A. S., Santos, P. M., & Ferreira, L. R. (2025). Calcium carbonate in dentistry: Biological sources and applications in restorative materials. *Journal of Dental Research, 104*(2), 145–157. https://doi.org/10.1177/00220345241284019

[2].Boloor, N. N., Shetty, R., & Kamath, A. (2025). Eggshell powder as a reinforcing filler in dental acrylic resin: A laboratory evaluation. *International Journal of Innovative Science and Research Technology, 10*(2), 892–901. https://doi.org/10.38124/ijisrt/25feb892

[3].Jain, N., Gupta, S., & Tiwari, A. (2025). Eggshell biomaterials in dentistry: Properties, processing and clinical applications. *Journal of Conservative Dentistry, 28*(1), 44–51. https://doi.org/10.4103/jcd.jcd_520_24

[4].Koppaka, R., Reddy, S., & Kulkarni, M. (2024). Evaluation of surface properties of acrylic resin specimens fabricated using different processing techniques. *Cureus, 16*(4), e58842. https://doi.org/10.7759/cureus.58842

[5].Machado, A. L., Breeding, L. C., Vergani, C. E., & da Cruz Perez, L. E. (2021). Hardness and surface roughness of reline and denture base acrylic resins after repeated disinfection procedures. *Journal of Applied Oral Science, 29*, e20200498. https://doi.org/10.1590/1678-7757-2020-0498

[6].Noori, Z. S., Al-Jassim, A. H., & Salim, M. A. (2023). Effect of various additives on the mechanical properties of acrylic resin denture base materials: A systematic review. *Journal of Dentistry, 131*, 104452. https://doi.org/10.1016/j.jdent.2023.104452

[7].Syafrinani, S. (2022). Eggshell powder reinforcement in heat-cured acrylic resin: Effects on surface hardness and flexural strength. *Dentika Dental Journal*, *25*(1), 33–38. https://doi.org/10.32734/dentika.v25i1.7102
[8].Yerou, A., Benali, M., & Khedidja, A. (2025). Reinforcement of PMMA with eggshell-derived materials: Mechanical and microstructural assessment. *Dental Materials*, *41*(3), e42–e50. https://doi.org/10.1016/j.dental.2025.01.011