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3D Printed Test Teeth Using PLA-Calcium Composite: an FDM Approach

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Abstract: Dental models are essential for education, research, and clinical practice, yet traditional fabrication methods like plaster casting lack flexibility and cost-efficiency. This study explores 3D printing of test teeth using a Polylactic Acid (PLA)-Calcium composite via Fused Deposition Modelling (FDM) to create realistic, durable, and cost-effective dental models. The composite enhances PLA's mechanical properties to mimic natural teeth, with calcium additives improving hardness and biocompatibility. The methodology involves CAD modelling, FDM printing with varied infill parameters, and mechanical testing (tensile, compression, and impact). Results show that a 50% infill density with a triangular pattern achieves optimal tensile strength (2.4921 MPa) and compressive strength (35.91 MPa), while an 80% infill maximizes impact toughness (1.7914 kJ/m^2). The study concludes that PLA-Calcium composites offer a viable alternative for dental model fabrication, supporting sustainable and customizable solutions for dental education and preclinical testing.

Keywords: 3D Printing, PLA-Calcium Composite, Fused Deposition Modelling, Dental Models, Mechanical Testing

Introduction

Dental models are critical tools in dental education, surgical planning, and material testing, traditionally produced using plaster or resin. These methods are labour-intensive, costly, and limited in design flexibility. Additive manufacturing, particularly 3D printing, offers a transformative approach by enabling rapid, precise, and customizable fabrication of dental structures. Fused Deposition Modelling (FDM), an economical 3D printing technique, is widely adopted for its accessibility and compatibility with biocompatible materials like Polylactic Acid (PLA).

This study focuses on 3D printing test teeth using a PLA-Calcium composite, where calcium additives enhance mechanical strength and mimic the mineral content of natural teeth. The objectives are to design anatomically accurate tooth models, optimize FDM printing parameters, and evaluate the composite's mechanical performance through tensile, compression, and impact tests. The outcomes aim to provide cost-effective, durable dental models for educational and preclinical applications, addressing the limitations of traditional methods.

Literature Review

The demand for accurate dental models has driven advancements in additive manufacturing. [1] highlighted that PLA, a biodegradable thermoplastic, is biocompatible but lacks the hardness required for dental applications. Incorporating calcium-based fillers, such as hydroxyapatite (HA) or calcium carbonate, improves stiffness and bioactivity [2]. [3] reported that PLA-HA composites significantly enhance tensile strength, while [4] demonstrated bone-like properties in PLA-HA scaffolds, supporting osteogenic differentiation.

FDM printing enables precise control over infill density and patterns, impacting mechanical performance [5]. Studies by [6] and [7] emphasize the hierarchical structure of natural teeth, with enamel (96% HA, hardness 3–6GPa) and dentin (elastic modulus 15–21GPa) requiring materials that balance hardness and toughness. PLA-Calcium composites address these needs by emulating tooth-like properties, making them suitable for dental training models.

Research Gap

While PLA-Calcium composites show promise, optimizing infill parameters and achieving microscale accuracy in FDM-printed dental models remain not explored. This study addresses these gaps by systematically evaluating the effects of infill density and patterns on mechanical properties, aiming to produce realistic test teeth for educational and research purposes.

Methodology

The methodology involves designing, fabricating, and testing 3D-printed test teeth using PLA-Calcium composite via FDM. The steps are outlined below:

1. Material Selection: PLA-Calcium composite filament (1.75 mm diameter) was chosen for its biocompatibility, printability, and enhanced mechanical properties due to calcium additives (e.g., calcium carbonate).

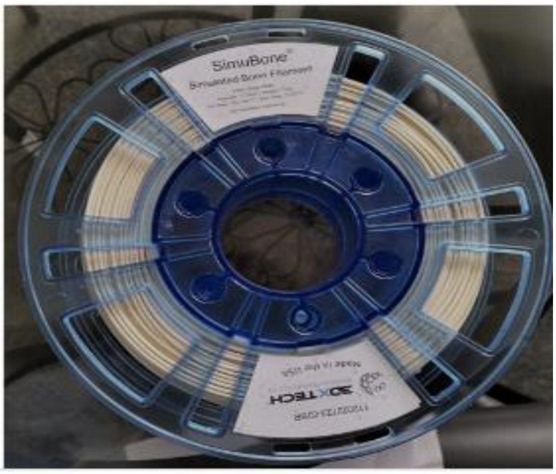

Figure 1: 1.75mm Diameter PLA-Calcium.

2. CAD Modelling: Tooth models were designed using CATIA, referencing high-resolution dental scans to ensure anatomical accuracy. Models were exported as STL files.

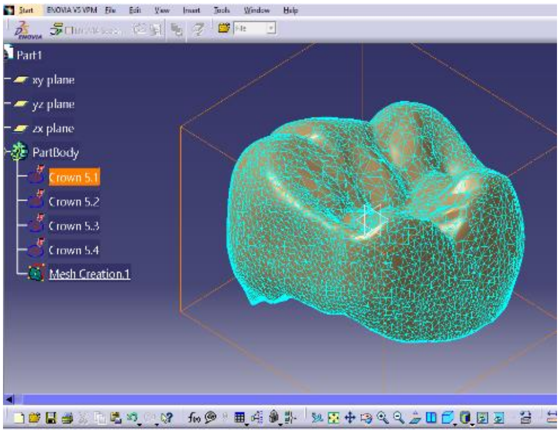

Figure 2: Teeth Design Using CATIA.

3. FDM Printing: An FDM printer was used with PLA-Calcium filament. Printing parameters included:

- Infill densities: 40%, 50%, 80%
- Infill Patterns: Triangular, Octo-gram
- Layer Height: 0.2 mm
- Nozzle Temperature: 200°C
- Bed Temperature: 60°C

Figure 3:3D Printing Machine

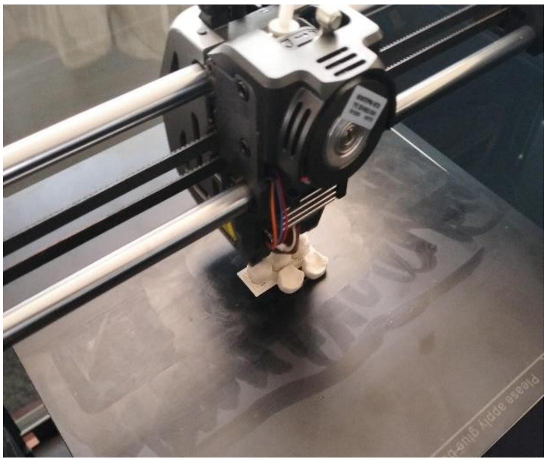

Figure 4: Surface Modification

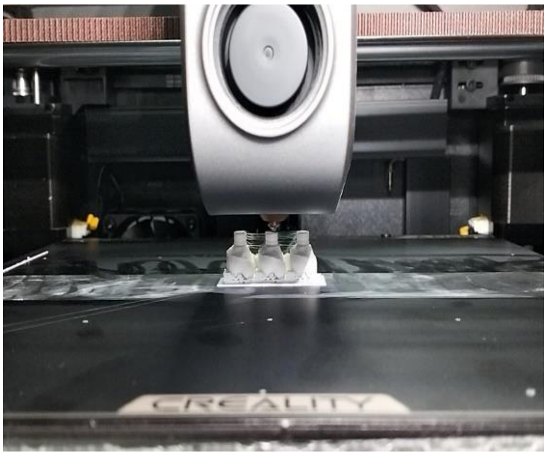

Figure 5: Process of Fabrication of Teeth

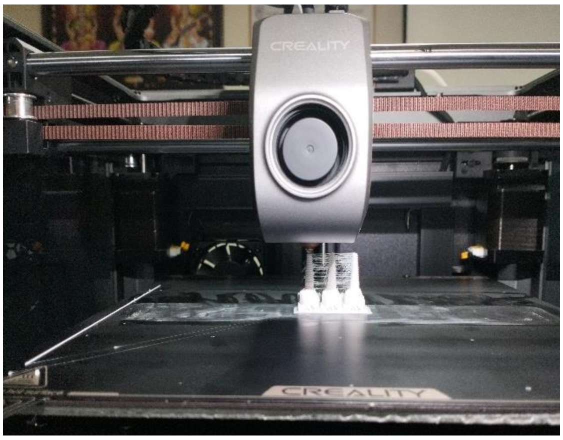

Figure 6: Completed Fabrication of Teeth

4. Post-Processing: Printed models were cleaned using isopropyl alcohol and ultrasonic baths, followed by air and vacuum drying to ensure surface quality.

5. Mechanical Testing:

- Tensile Testing: Conducted per ASTM D638 on Type I specimens (165 × 13 × 3.2 mm) at 4mm/min.

- Compression Testing: Performed per ASTM D695 on specimens (12.7 × 12.7 × 25.4 mm).

- Impact Testing: Executed per ASTM D256 on specimens (63.5 × 12.7 × 3.2 mm) using a pendulum tester.

6. Statistical Analysis: Analysis of Variance (ANOVA) was used to assess the significance of infill parameters on mechanical properties.

Figure 7: 3D printed model

Results and Discussion

Chemical and Physical Properties

The PLA-Calcium composite exhibited biocompatibility and enhanced hardness due to calcium carbonate, mimicking the mineral content of enamel (96% HA). The filament's printability was consistent, with no nozzle clogging at 200°C.

1. Tensile Strength

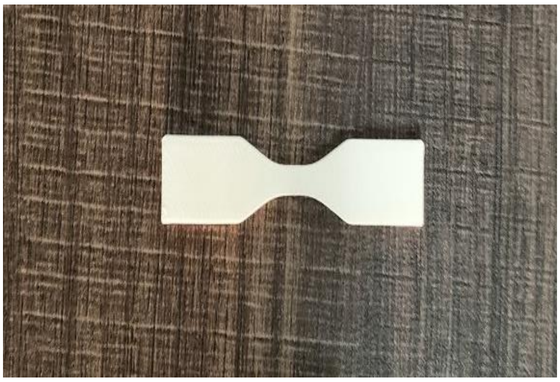

Figure 8: Tensile Specimen

Tensile tests (Table 1) showed that triangular infill at 50% density achieved the highest tensile strength (2.4921 MPa) and elongation (1.9262%). Octo-gram infill at 50% density also performed well (2.2439 MPa), but higher densities (80%) reduced elongation due to increased brittleness.

Table 1: Tensile strength results

Materials	Infill pattern	Infill density	Energy absorption in J	% of Elongation
PLA-Calcium	Triangle	40%	0.2144	0.7157
PLA-Calcium	Triangle	50%	0.4914	0.9928
PLA-Calcium	Triangle	80%	0.8057	1.6278
PLA-Calcium	Octo-gram	40%	0.2054	0.6823
PLA-Calcium	Octo-gram	50%	0.5364	1.1829
PLA-Calcium	Octo-gram	80%	0.8946	1.7914

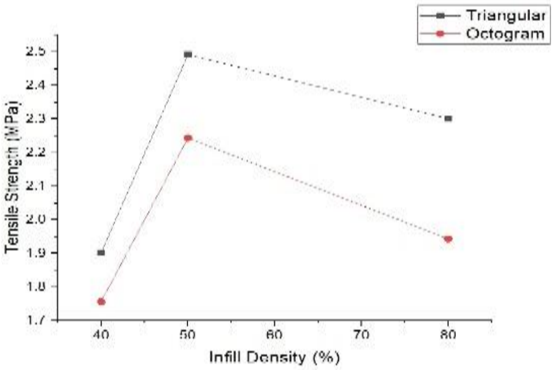

Figure 9: Tensile Strength Graph Infill Density V/S Tensile Strength

2. Impact Strength

Figure 10: Impact test Specimen

Impact tests (Table 2) revealed that octo-gram infill at 80% density yielded the highest impact strength (1.7914 kJ/m^2), indicating better resistance to sudden forces. Triangular infill at 80% density also performed well (1.6278 kJ/m^2).

Table 2: Impact strength results

Materials	**Infill pattern**	**Infill density**	**Energy absorption in J**	**Impact strength J/mm^2**
PLA-Calcium	Triangle	40%	0.2144	0.7157
PLA-Calcium	Triangle	50%	0.4914	0.9928
PLA-Calcium	Triangle	80%	0.8057	1.6278
PLA-Calcium	Octo-gram	40%	0.2054	0.6823
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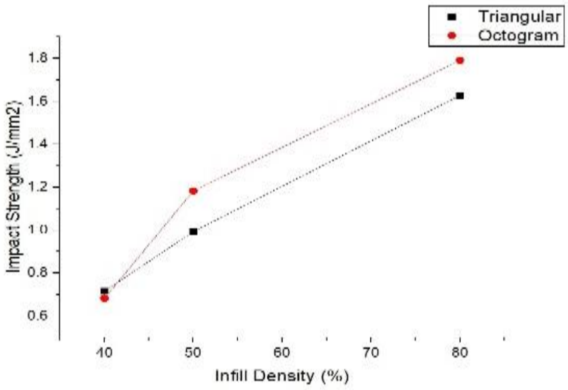

Figure 11: Impact Strength Graph Infill Density V/S Impact Strength

3. Compression Strength

Figure 12: Compression test Specimen

Compression tests (Table 3) showed that triangular infill at 80% density achieved the highest compressive strength (43.34 MPa) with minimal length reduction (2.36%). Octo-gram infill at 80% density was slightly lower (37.41 MPa), indicating triangular infill's superior load-bearing capacity.

Table 3: compression strength results

Materials	**Infill pattern**	**Infill density**	**Compr -ession strength MPa**	**% of Reduction in Length**
PLA-Calcium	Triangle	40%	29.32	2.78%
PLA-Calcium	Triangle	50%	35.91	2.49%
PLA-Calcium	Triangle	80%	43.34	2.36%
PLA-Calcium	Octo-gram	40%	27.61	3.17%
PLA-Calcium	Octo-gram	50%	32.85	2.70%
PLA-Calcium	Octo-gram	80%	37.41	2.58%

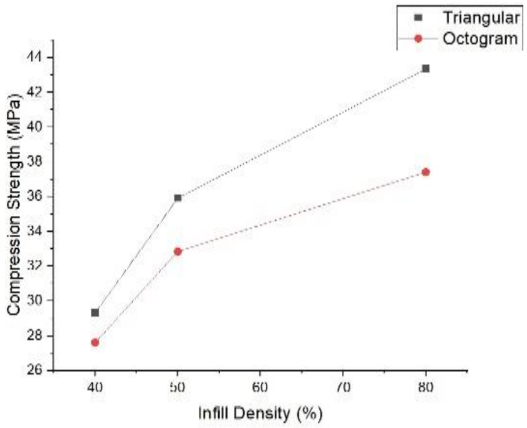

Figure 13: Compressive Strength Graph Infill Density V/S Compressive Strength

Discussion

The results indicate that infill density and pattern significantly affect mechanical performance. A 50% triangular infill optimizes tensile strength and elongation, suitable for simulating dentin's elasticity (15–21GPa). An 80% octo-gram infill maximizes impact toughness, mimicking enamel's resistance to fracture (0.6–1.5 $MPa \cdot m^{0.5}$). Compressive strength peaks at 80% triangular infill, aligning with dentin's compressive strength (100–150 MPa). However, the composite's tensile strength (1.7–2.5 MPa) is lower than natural teeth, suggesting the need for further calcium optimization or alternative fillers like HA.

ANOVA analysis confirmed that infill density has a statistically significant effect ($p < 0.05$) on all mechanical properties, with pattern influencing impact toughness more than tensile or compressive strength. The PLA-Calcium composite's biocompatibility and printability make it ideal for educational models, but its mechanical properties require enhancement for clinical applications.

Challenges and Limitations

- Mechanical Properties: The PLA-Calcium composite's tensile strength is lower than natural teeth, limiting its use in load-bearing applications.
- Microarchitecture: FDM struggles to replicate enamel-dentin interfaces and nanoscale HA crystals, affecting anatomical realism.
- Biodegradability: Controlling degradation rates to match dental tissue regeneration is challenging.
- Scalability: Producing uniform models at scale is time-intensive due to post-processing requirements.
- Hurdles: Clinical adoption requires rigorous testing for biocompatibility and long-term stability.

Future Scope

Future research should focus on:

- Incorporating higher HA content or bioactive glass to enhance mechanical strength and bioactivity.
- Using high-resolution printing techniques (e.g., SLA) for finer microarchitecture.
- Integrating AI for automated design optimization and predictive modelling.
- Conducting long-term studies on degradation and oral environment interactions.
- Exploring bioprinting with cell-laden materials for regenerative dentistry.

Conclusion

This study demonstrates that 3D printing test teeth using PLA-Calcium composite via FDM is a viable approach for producing cost-effective, customizable dental models. Optimal parameters include 50% triangular infill for tensile strength (2.4921 MPa) and 80% infill for compressive strength (43.34 MPa) and impact toughness (1.7914 kJ/m^2). While the composite mimics some properties of natural teeth, its mechanical strength requires improvement for clinical applications. The findings support the use of PLA-Calcium composites in dental education and preclinical testing, contributing to sustainable and innovative dental model fabrication.

References

[1] Backes, E.H., et al., "Polylactic Acid Composites for Dental Applications," J. Mater. Sci., 2020.

[2] Plamadiala, P., et al., "Calcium-Reinforced PLA for 3D Printing Dental Models," Addit. Manuf., 2025.

[3] Custodio, R., et al., "Mechanical Enhancement of PLA-HA Composites," Biomaterials, 2021.

[4] Bernardo, A., et al., "PLA-HA Scaffolds for Bone Regeneration," J. Biomed. Mater. Res., 2022.

[5] Kamio, T., et al., "Infill Optimization in FDM Dental Models," Dent. Mater., 2024.

[6] Delgado-Ruiz, R., Romanos, G., "Tooth Structure and Mechanical Properties," J. Prosthodont., 2018.

[7] He, L.H., Swain, M.V., "Nano-Mechanics of Teeth," J. Mech. Behav. Biomed. Mater., 2007.

[8] Hull, C.W., "Apparatus for Production of Three-Dimensional Objects by Stereolithography," Google Patents, 1986.

[9] Nyberg, et al., "3D-Printing Technologies for Craniofacial Rehabilitation," Ann. Biomed. Eng., 45(1), 2017.

[10] Murphy, S.V., Atala, A., "3D Bioprinting of Tissues and Organs," Nat. Biotechnology, 32(8), 2014.