INVESTIGATING THE MECHANICAL PROPERTIES OF ZrO_2 & TiO_2 IMPREGNATED PMMA NANOCOMPOSITES FOR DENTURE BASE

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Introduction:

Polymethyl methacrylate (PMMA) has long been a staple material in dental applications due to its excellent aesthetic qualities, ease of processing, and cost-effectiveness. However, PMMA suffers from mechanical limitations such as low tensile and flexural strength, poor wear resistance, and vulnerability to microbial adhesion, which limits its long-term functionality in prosthodontics. To overcome these issues, this project investigates the incorporation of zirconium dioxide (ZrO_2) and titanium dioxide (TiO_2) nanoparticles into PMMA to form nanocomposites. These nanoparticles, known for their high mechanical strength and antimicrobial properties, offer promising enhancements in structural and biological performance. The project explores varying concentrations of ZrO_2 and TiO_2 to identify the optimal composition that improves the strength, wear resistance, and surface morphology of PMMA. The outcome has potential applications in next-generation denture base materials and broader biomedical fields.

Objectives:

- To synthesize PMMA nanocomposite reinforced with varying concentrations of ZrO_2 and TiO_2 nanoparticles

- Fabrication of the dies (flexural, tensile, compression & wear)according to the ASTM standards.
- To evaluate the mechanical properties (flexural strength, tensile strength, and compressive strength) of the synthesized nanocomposite.
- To assess the wear resistance of the PMMA nanocomposites.
- To conduct Scanning Electron Microscopy (SEM) analysis to observe this dispersion of nanoparticles within the PMMA matrix and study the surface morphology

Methodology:

The project commenced with procuring the required raw materials for this study were carefully procured from reliable sources to ensure consistency and quality throughout the experimental process. These included Polymethyl methacrylate (PMMA) powder and its corresponding liquid monomer (hardener) for the cold cure acrylic method, Zirconium dioxide (ZrO_2) and Titanium dioxide (TiO_2) nanoparticles—selected for their nanoscale size, mechanical reinforcement, and antimicrobial properties—and mold-release wax, which was applied to the dies to facilitate smooth removal of cured specimens without surface damage. Additionally the Computer Aided Design (CAD) of test dies for tensile (ASTM D638), flexural (ASTM D790), compression (ASTM 695), and wear tests (ASTM G99) using Fusion 360.

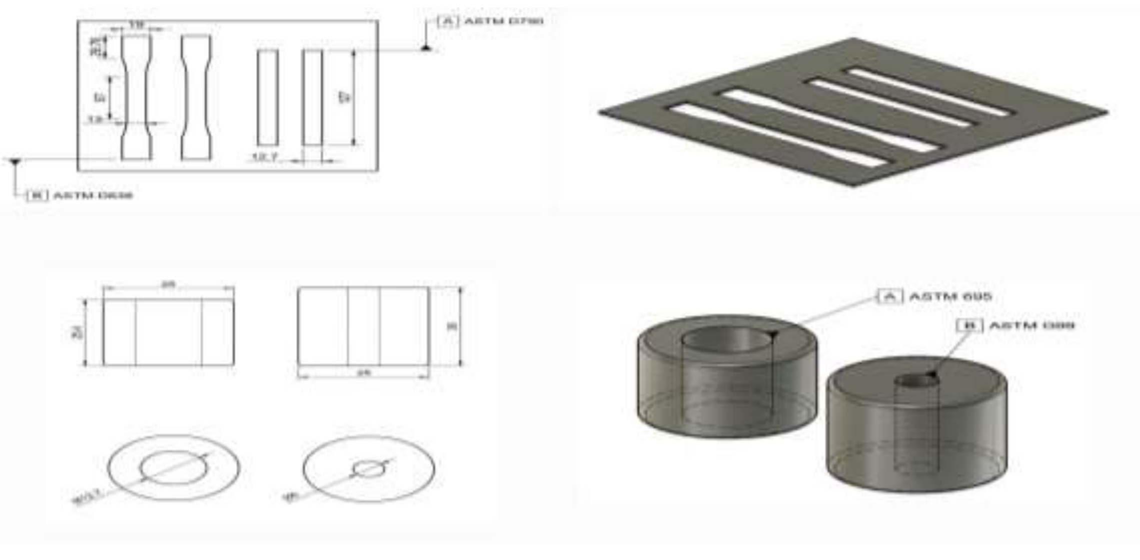

Figure 1: Tensile, Flexural, Compression & Wear Die CAD designed in Fusion 360

Fabrication was carried out using laser cutting for flexural and tensile dies, and drilling operations for compression and wear dies on 25 mm diameter cylindrical rods. PMMA powder was measured based on the die volumes, and ZrO_2 and TiO_2 nanoparticles were added in different weight percentages. The nanocomposites were synthesized using the cold cure acrylic method, mixing powder and hardener in a 1:1 ratio and casting them into wax-coated dies. A total of 60 specimens were prepared (3 samples for each of 5 concentrations across 4 tests). All mechanical tests were performed using UTM and pin-on-disk setups, and the results were evaluated for performance metrics. Additionally, four specimens were prepared for SEM analysis with 10x10x3 mm dimensions and examined at Nitte Meenakshi Institute of Technology, Bengaluru, under 100x and 500x magnification to analyze surface morphology and nanoparticle dispersion.

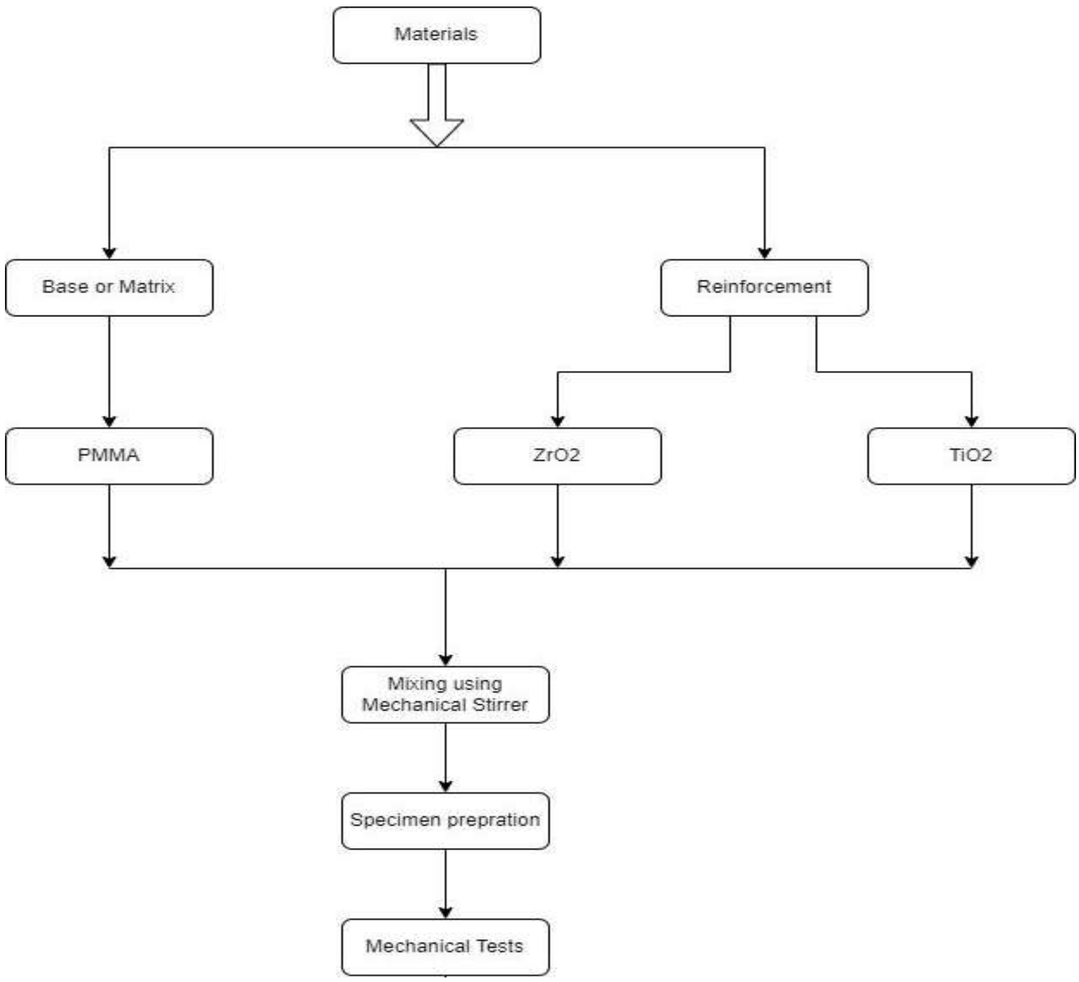

Figure 2: Methodology

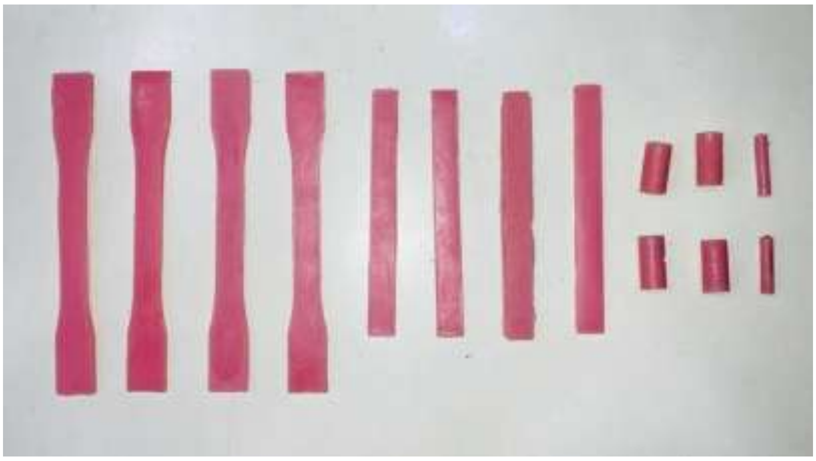

Figure 3: PMMA Nanocomposites specimens

Result and Conclusion:

The results demonstrated significant enhancement in mechanical properties with increasing nanoparticle concentration. Tensile strength increased from 445.12 Kg/cm² (pure PMMA) to 540.76 Kg/cm² at 1.0 wt%. Flexural strength peaked at 1387.23 Kg/cm², and compressive strength reached 856 Kg for the highest concentration. Wear resistance improved across all concentrations. SEM imaging confirmed uniform dispersion of nanoparticles, reduction in porosity, and improved surface morphology, especially at 0.75 wt%. The optimal nanoparticle loading was observed at 0.75 wt% for maintaining a balance between strength and flexibility. These enhancements validate the potential of ZrO_2 and TiO_2 nanoparticles in overcoming the limitations of PMMA in dental applications.

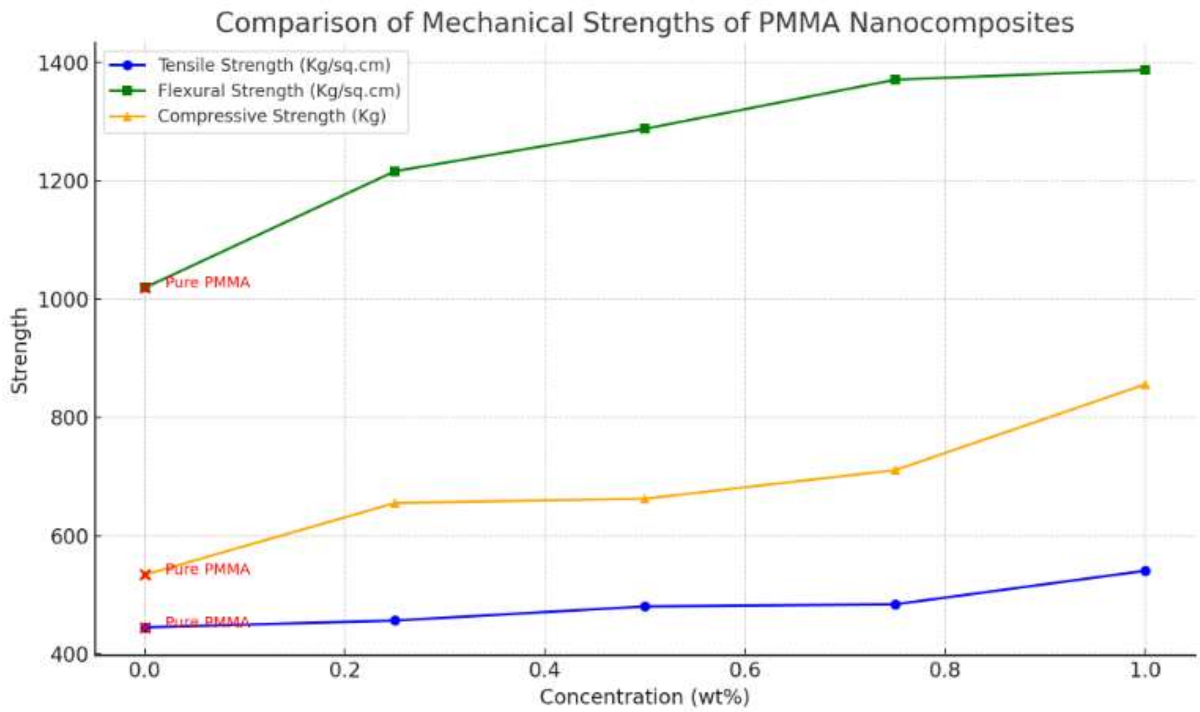

Figure 4: Graph of Mechanical Strength vs Concentration

The graph illustrates the mechanical performance of PMMA nanocomposites with varying concentrations (0.0–1.0 wt%) of ZrO_2 and TiO_2 nanoparticles. As the concentration increases, tensile, flexural, and compressive strengths show a consistent upward trend. This indicates that nanoparticle reinforcement significantly enhances the overall mechanical properties of PMMA. Pure PMMA consistently exhibits the lowest strength values across all tests.

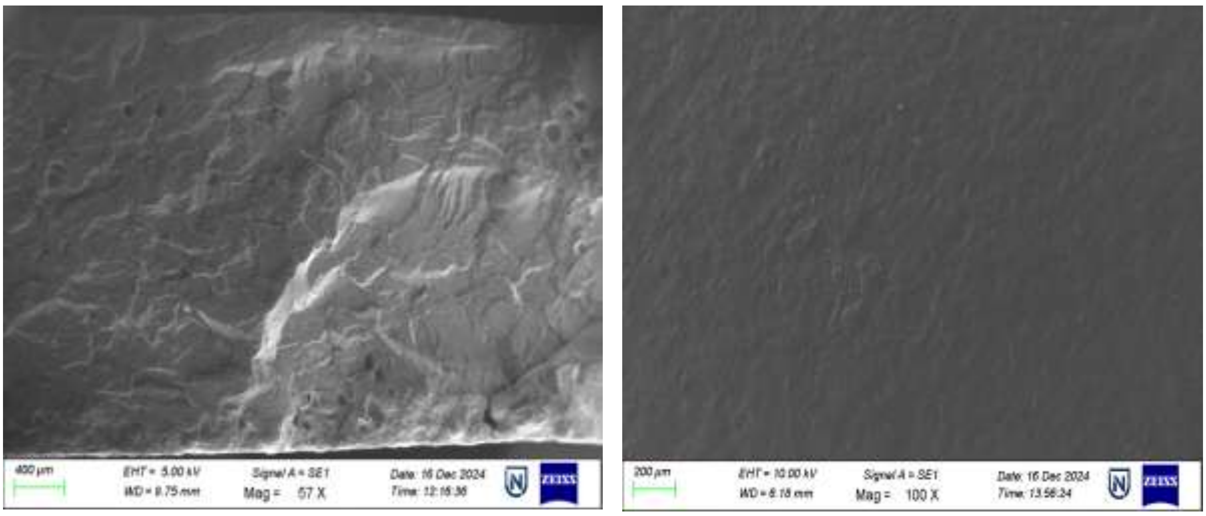

Figure 5: SEM Images

The SEM images represent the microstructural evaluation of PMMA nanocomposites. The first image (57x) shows the fractured surface, revealing uneven morphology and crack propagation, indicating brittle fracture behavior. The second image (100x) displays a smoother top surface, suggesting uniform particle distribution and proper polymerization. Together, they confirm the structural integrity and effective nanoparticle dispersion in the composite.

The experimental results demonstrate that reinforcing PMMA with ZrO_2 and TiO_2 nanoparticles significantly enhances its mechanical and wear properties. As the nanoparticle concentration increased, improvements were observed in tensile, flexural, and compressive strengths, with the highest performance recorded at 1.0 wt%. The wear rate consistently decreased with increasing filler content, indicating enhanced resistance to material loss under load and sliding conditions. SEM analysis further confirmed effective nanoparticle dispersion and improved structural integrity. These findings suggest that PMMA nanocomposites, particularly with 0.75–1.0 wt% filler concentration, are promising for applications requiring superior strength and durability, such as in dental prosthetics.

Project Outcome & Industry Relevance:

This project successfully demonstrates how nanotechnology can enhance traditional dental materials. The reinforced PMMA nanocomposites show improved mechanical, wear, and antimicrobial properties, making them ideal for denture base applications. Industries involved in dental prosthetics and biomedical materials can adopt this method to produce more durable and hygienic products. The research has direct relevance in prosthodontics, dental labs, and bioengineered material sectors, paving the way for advanced, patient-safe materials.

Working Model vs. Simulation/Study:

This project is a research-based experimental study focused on the investigation of mechanical and wear properties of ZrO_2 & TiO_2 reinforced PMMA nanocomposites.

Project Outcomes and Learnings:

- Developed 60 nanocomposite samples and tested mechanical and surface properties.

- Learned material fabrication techniques, CAD modeling, and testing under ASTM standards.
- Understood the significance of nanoparticle dispersion and surface analysis using SEM.
- Gained hands-on experience in experimental design, data analysis, and technical reporting.

Future Scope:

Future work could explore the long-term biocompatibility and aging performance of these nanocomposites in oral conditions, including moisture and pH variations. Further investigations can include antimicrobial testing against oral pathogens to confirm the antibacterial efficiency of TiO_2. Exploring hybrid nanoparticles and their synergistic effects may yield even greater enhancements in strength and flexibility. Additionally, developing 3D printable formulations of these nanocomposites could revolutionize chair-side fabrication of dental prosthetics. Collaborations with dental labs and materials scientists could transform this lab-scale work into industrial applications and clinical trials.

The potential of PMMA nanocomposites reinforced with ZrO_2 and TiO_2 nanoparticles opens new avenues for research and application in the field of dental materials. While this project demonstrated significant improvements in mechanical properties, wear resistance, and surface characteristics, further advancements can be pursued to optimize and expand the applications of these materials.

1. Optimization of Nanoparticle Concentrations
2. Long-term Performance Analysis
3. Antimicrobial Properties Evaluation
4. Exploration of Other Nanoparticles
5. Application in Advanced Prosthetics
6. Surface Treatment Techniques
7. Development of Sustainable Materials