The Influence of Silanized ZrO2 Fillers on the Impact Resistance of Artificial Tooth Composites

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**Abstract.** Dental health remains a critical concern in Indonesia, with a high prevalence of dental damage affecting a significant portion of the population. Prosthetic dentistry plays a crucial role in restoring oral function and aesthetics, with polymethyl methacrylate (PMMA) being a commonly used material despite its limitations in impact resistance. This study explores the incorporation of silanized zirconia dioxide (ZrO2) fillers into PMMA artificial tooth composites to enhance their mechanical properties. ZrO2 nanoparticles were silanized with γ-methacryloxypropyltrimethoxysilane (γ-MPS) and integrated into PMMA using suspension polymerization. Impact strength testing, conducted according to ASTM D6110 standards, revealed that composites with ZrO2 concentrations of 2%, 3%, 4%, and 5% achieved impact strengths meeting ISO 22112:2016 standards (2 kJ/m²), with the highest impact strength observed at 5% ZrO2. FTIR analysis confirmed strong chemical bonding between ZrO2 and PMMA, enhancing material strength and durability while maintaining an aesthetically pleasing natural white color resembling real teeth. This research highlights the potential of ZrO2-modified PMMA composites as durable and aesthetically superior alternatives in prosthetic dentistry, addressing both functional and aesthetic needs effectively. **Keywords:** Denture Teeth, Zirconium, Silane Coupling Agent, Heat Cured Polymerization

# INTRODUCTION

The development of artificial teeth has seen significant advancements in addressing the limitations of traditional materials. Resin-based artificial teeth, particularly those made from polymethyl methacrylate (PMMA), have gained popularity due to their affordability, lightweight nature, and crack resistance compared to ceramic counterparts[1]. However, their susceptibility to wear presents a challenge in achieving long-term functionality and durability. To overcome this, researchers have explored the incorporation of zirconia (ZrO2) nanoparticles into the PMMA matrix as a potential solution[2].

ZrO2 nanoparticles are widely recognized for their biocompatibility, high fracture resistance, and superior dispersion properties. When reinforced in PMMA using the silane coupling agent γ-MPS, these nanoparticles form a strong bond between the inorganic ZrO2 and the organic PMMA matrix[3]. This integration significantly enhances the mechanical and functional properties of the composite material. Additionally, the uniform distribution, fine particle size, and high interfacial shear strength between ZrO2 nanoparticles and the PMMA matrix contribute to improved wear resistance and overall performance[4].

In this study, a novel composite artificial tooth was developed by incorporating ZrO2 nanoparticles into PMMA. Unlike previous studies, this work focuses on optimizing the performance of ZrO2-reinforced nanocomposites by investigating the effects of silanization levels and filler concentrations. By examining the interactions between ZrO2 and the PMMA matrix, this study provides novel insights into achieving a balanced enhancement of physical and mechanical properties, contributing to the development of more durable resin-based dentures.

# MATERIALS AND METHODS

## Materials

The materials utilized in this study included analytical-grade methyl methacrylate (MMA, 99%) obtained from Sigma-Aldrich, serving as the monomer after undergoing vacuum distillation as a purification step. Technical-grade polyvinyl alcohol (PVA) and distilled water were prepared and used in the synthesis process. Benzoyl peroxide (BPO) initiators, sourced from Sigma-Aldrich, were employed to initiate the polymerization reaction. Additionally, technical- grade ethanol with a purity of 98% was employed in the experimental setup. Zirconium oxide from Sigma-Aldrich was utilized as the filler material, while γ-methacryloxypropyltrimethoxysilane (γ-MPS) was employed for silanization. Ethylene glycol dimethacrylate (EGDMA) served as the cross-linking agent in the composite material synthesis.

## Methods

In this study, suspension polymerization was employed to produce polymethyl methacrylate (PMMA) particles, followed by a washing procedure using an ethanol-water mixture. The resulting PMMA particles were combined with 1%, 2%, 3%, 4%, and 5% by weight zirconium oxide (ZrO2) fillers that had been silanized with 5% γ- methacryloxypropyltrimethoxysilane (γ-MPS) using a V-type blender to achieve a homogeneous solid mixture. Subsequently, a liquid phase was prepared by combining methyl methacrylate (MMA) and ethylene glycol dimethacrylate (EGDMA). The powder-to-liquid ratio used was 2.5:1. The solid and liquid components were then mixed in a stainless-steel bowl until a homogeneous dough stage was reached.

# RESULT AND DISCUSSION

ZrO2 nanoparticles, known for their biocompatibility, high fracture resistance, and optimal particle dispersion, are reinforced in PMMA artificial teeth using the silane coupling agent γ-MPS. γ-MPS effectively bridges the bond between inorganic and organic materials, enhancing the mechanical and functional properties of the composite [5]. This improvement is attributed to the phase transformation from tetragonal to monoclinic ZrO2, which absorbs crack energy. The uniform distribution, fine size, and high surface shear strength between the nanoparticles and the matrix allow the nanoparticles to integrate into the polymer chains, preventing cracks and enhancing the mechanical and functional properties of the PMMA artificial teeth [6], [7].

**FIGURE 1** illustrates the production outcome of the composite artificial tooth, displaying a white color that closely resembles the natural shade of teeth. This composite has been meticulously designed to match the color, texture, and luster of real teeth, providing a highly aesthetic and natural appearance. In the fabrication process, this artificial tooth composite not only offers optimal color matching but also exhibits high strength and durability. The results shown in the figure demonstrate the composite's ability to achieve a uniform white color, making it an ideal choice for tooth replacements that are both functional and aesthetically pleasing.

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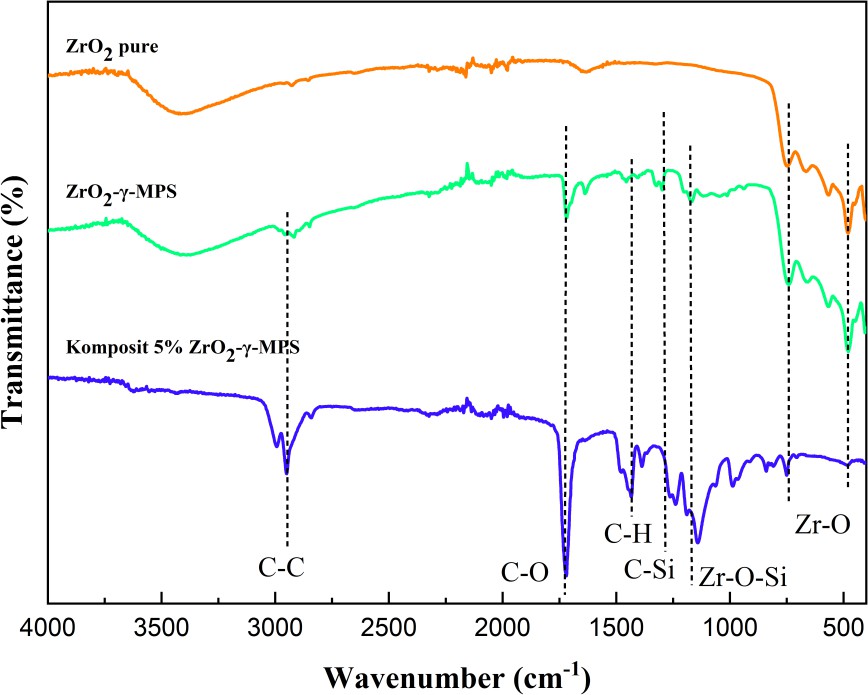
**FIGURE 1.** Result of Artificial Tooth Composites

## Fourier-Transform Infrared Spectroscopy

FTIR analysis, as shown in **FIGURE 2**, was conducted to investigate the metal-oxygen and carbon-oxygen bonds in the silanization of ZrO2 with γ-MPS and in the resulting artificial tooth composite. The analysis revealed a broad peak at 3414 cm⁻¹ in both ZrO2 and ZrO2-γ-MPS, indicating the stretching of hydroxyl (O-H) bonds.

The FTIR spectrum of ZrO2 nanoparticles displayed sharp and strong stretching vibration bonds at 750 cm⁻¹ and 673 cm⁻¹, signifying the presence of metal-oxygen Zr-O bonds [8]. Upon silanization, new peaks emerged, such as at 1162 cm⁻¹ and 1294 cm⁻¹, indicating hydroxyl groups in Zr-O-Si and C-Si groups from the hydrolysis of Si-O-CH3 groups [9]. Peaks at 1321 cm⁻¹, 1400-1650 cm⁻¹, 1717 cm⁻¹, and 2840-3000 cm⁻¹ were attributed to C- H, C-C=C, C=O, and C-H bonds from the γ-MPS monomer [10], indicating interactions between γ-MPS and ZrO2 in ZrO2-γ-MPS.

The resulting artificial tooth composite exhibited similar peaks to ZrO2-γ-MPS, along with sharp C-C and C-O peaks, indicating the main matrix of the artificial tooth. This analysis confirms that the composite successfully integrated silanized ZrO2 with γ-MPS, resulting in a material with strong and stable chemical bonds. Consequently, this artificial tooth composite not only offers an aesthetic appearance resembling natural teeth but also enhanced strength and durability, making it ideal for clinical applications in dentistry.



**FIGURE 2.** FTIR Analysis Results

## Impact Strength Analysis

Impact Strength analysis was conducted to determine the resistance of PMMA artificial teeth to sudden impacts or pressure. This analysis is crucial to ensure that the artificial teeth can withstand the forces encountered during eating or chewing hard foods, endure impacts from accidental drops that could cause damage, and resist frictional forces between the artificial teeth and oral tissues, which could lead to wear. For the Impact Strength analysis of PMMA artificial teeth, the ASTM D6110 standard for acrylic materials was used with dimensions of 55 mm x 10 mm x 10 mm and a 45° notch. The impact strength testing results are listed in **TABLE 1** and **TABLE 2.** The testing was performed with varying concentrations of γ-MPS at 5% and ZrO2 at 1%, 2%, 3%, 4%, and 5%, and a powder-to-liquid (P/L) ratio of 2.5:1.

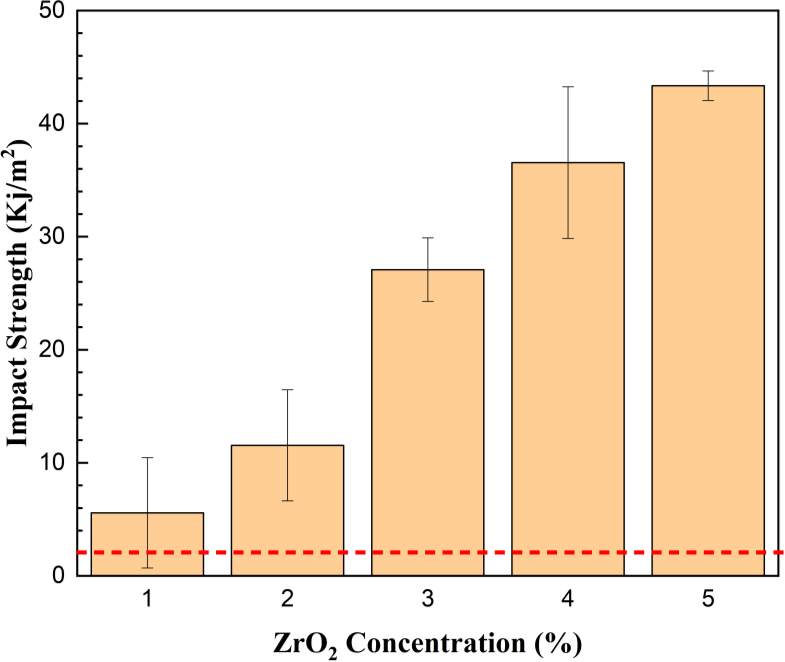
**TABLE 1.** Impact Strength Values without Silanization

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **ZrO2 Concentration** | **E (J)** | **IS (kJ/m2)** | **IS avg** | **St. dev** |
|  | 0.0000 | 0.0000 |  |  |
| 0% | 0.1705 | 0.0021 | 0.7018 | 0.9925 |
|  | 0.0000 | 0.0000 |  |  |
|  | 0.0853 | 0.0010 |  |  |
| 5% | 0.0000 | 0.0000 | 0.2424 | 0.4843 |
|  | 0.0000 | 0.0000 |  |  |

**TABLE 2.** Impact Strength Values with Silanization at Different ZrO2 Concentrations

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **ZrO2 Concentration** | **E (J)** | **IS (kJ/m2)** | **IS avg** | **St. dev** |
|  | 0.1705 | 0.0021 |  |  |
| 1% | 0.1705 | 0.0021 | 5.5713 | 4.8831 |
|  | 1.0231 | 0.0125 |  |  |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | 1.5345 | 0.0185 |  |  |
| 2% | 0.6821 | 0.0081 | 11.5445 | 4.9102 |
|  | 0.6821 | 0.0080 |  |  |
|  | 2.2162 | 0.0258 |  |  |
| 3% | 2.1310 | 0.0245 | 27.0843 | 2.8102 |
|  | 2.7271 | 0.0310 |  |  |
|  | 2.9825 | 0.0335 |  |  |
| 4% | 2.7271 | 0.0303 | 36.5561 | 6.7057 |
|  | 4.1729 | 0.0459 |  |  |
|  | 4.0030 | 0.0435 |  |  |
| 5% | 4.1729 | 0.0449 | 43.3541 | 1.3067 |
|  | 3.9180 | 0.0417 |  |  |

The overall results of the Impact Strength analysis are presented in a bar chart in **FIGURE 3.** It is evident that the higher the concentration of ZrO2 added to the PMMA artificial tooth composite, the higher the impact strength values obtained. According to the analysis, composites with ZrO2 concentrations of 2%, 3%, 4%, and 5% meet the minimum impact strength requirement for artificial teeth as per ISO 22112:2016, which is 2 kJ/m². This indicates that the addition of ZrO2 enhances the impact resistance of PMMA artificial teeth against sudden impacts or pressures.

**FIGURE 3.** Impact Strength

The inclusion of ZrO2 nanoparticles not only significantly increases the impact strength values but also demonstrates a positive correlation between the increasing concentration of ZrO2 and the improvement in material strength. Thus, the use of ZrO2 in artificial tooth composites not only complies with international standards but also offers additional benefits in terms of durability and resistance to challenging mechanical conditions. These results suggest that ZrO2-modified artificial tooth composites could be a more durable and reliable option for clinical applications.

# CONCLUSION

This study successfully incorporated silanized zirconia nanoparticles into PMMA artificial tooth composites, significantly improving both their aesthetics and mechanical properties. The addition of nanoparticles, facilitated by a coupling agent, led to stronger and more impact-resistant artificial teeth that meet international standards.

Additionally, the composites achieved a natural white color, resembling real teeth. Chemical analysis confirmed strong bonding between the components, ensuring long-term stability. Overall, these findings suggest ZrO2-modified PMMA composites as a promising alternative for artificial teeth, offering both superior durability and aesthetics. This advancement has the potential to significantly improve patient outcomes by providing strong and natural-looking prosthetic solutions. Further research can optimize these materials and validate their clinical performance for real- world applications.

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