Properties of Glass Ionomer Cement Loaded With ZrO2 Nanoparticles

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**Abstract:** Glass ionomer cements (GICs) are widely utilized in dentistry for their biocompatibility and fluoride release capabilities but often exhibit inferior mechanical properties. Incorporating zirconia (ZrO2) nanoparticles into GICs presents a promising strategy to enhance their mechanical strength, wear resistance, and fracture toughness while preserving biocompatibility and fluoride release. This study explores the synthesis of ZrO2 nanoparticles and their integration into GICs to evaluate the resultant material's properties. ZrO2 nanoparticles were synthesized via a sol-gel method using Zirconium nitrate and Ethylenediamine under ultrasonication. The nanoparticles were characterized using X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and field emission scanning electron microscopy (FESEM). These nanoparticles were then incorporated into GICs, and the composites were tested for mechanical properties, surface roughness, and wettability. XRD confirmed the crystalline nature of ZrO2 nanoparticles, FTIR identified surface functional groups, and FESEM revealed nanoparticle morphology. Incorporation of ZrO2 nanoparticles into GICs increased surface roughness and enhanced wettability. Mechanical testing showed improved flexural strength and microhardness compared to standard GICs. The enhanced mechanical properties of ZrO2-loaded GICs can be attributed to the reinforcing effect of nanoparticles and their uniform distribution within the cement matrix. The observed increase in surface roughness may enhance mechanical interlocking with dental substrates but requires consideration for potential impacts on plaque accumulation. Biocompatibility and fluoride release remained intact, affirming the suitability of these composites for dental applications. Incorporating ZrO2 nanoparticles into GICs significantly improves their mechanical properties without compromising biocompatibility or fluoride release. These findings highlight the potential of ZrO2-reinforced GICs to address the limitations of traditional materials and expand their utility in demanding dental restorations. Further optimization of nanoparticle concentration and dispersion techniques could enhance the clinical efficacy and longevity of these advanced dental materials.

# Introduction

Glass ionomer cements (GICs) are widely used in dentistry for their excellent adhesive properties, biocompatibility, and ability to release fluoride, which helps in remineralizing tooth structures and preventing secondary caries [(Harsha & Subramanian, 2022)](https://paperpile.com/c/gD9h08/0ZVt); [(Deepika et al., 2022)](https://paperpile.com/c/gD9h08/RLWxf)[(Solanki et al., 2022)](https://paperpile.com/c/gD9h08/JhiEx). However, their mechanical properties, such as wear resistance and strength, are often inferior compared to other restorative materials like composites and amalgams. To address these limitations, researchers have explored the incorporation of various fillers to enhance the performance of GICs. One promising approach involves loading GICs with zirconia (ZrO2) particles.[(Sampurnam et al., 2024)](https://paperpile.com/c/gD9h08/OoRd7)

Zirconia is a ceramic material known for its high fracture toughness, hardness, and biocompatibility. Incorporating ZrO2 particles into GICs aims to improve their mechanical properties while maintaining or even enhancing their beneficial characteristics, such as fluoride release and adhesion to dental tissues [(Chidambaram et al., 2022)](https://paperpile.com/c/gD9h08/ajPX); [(Ajay, Sasikala, et al., 2022)](https://paperpile.com/c/gD9h08/2lNwJ). Studies have shown that ZrO2-reinforced GICs exhibit improved compressive strength, flexural strength, and wear resistance, making them more suitable for high-stress-bearing areas in the oral cavity .The modification of GICs with ZrO2 particles can also influence their setting reaction and microstructure. The interaction between the glass ionomer matrix and zirconia particles is crucial in determining the overall properties of the resultant composite material.[(Maliael et al., 2021)](https://paperpile.com/c/gD9h08/h0uVD)

Research indicates that the optimal particle size and concentration of ZrO2 are critical factors in achieving the desired enhancement in properties without compromising the material’s workability and aesthetic qualities[(Ajay, Rakshagan, et al., 2022)](https://paperpile.com/c/gD9h08/avAC7). Loading glass ionomer cements with ZrO2 particles represents a significant advancement in dental materials science. This modification has the potential to produce restorative materials with superior mechanical properties while retaining the intrinsic benefits of GICs thereby expanding their applicability in clinical dentistry.[(Lakshmi, 2021; Sampurnam et al., 2023)](https://paperpile.com/c/gD9h08/6XDL7+xTgWj)

[(Harsha et al., 2022)](https://paperpile.com/c/gD9h08/kR5wH) **Enhanced Mechanical Properties:** The incorporation of zirconia (ZrO2) particles into glass ionomer cements (GICs) significantly enhances their mechanical properties. Studies have shown improvements in compressive strength, flexural strength, and wear resistance.[(Chidambaram et al., 2022)](https://paperpile.com/c/gD9h08/ajPX).[(Ajay, Sasikala, et al., 2022)](https://paperpile.com/c/gD9h08/2lNwJ) These enhancements make ZrO2-reinforced GICs more suitable for applications in high-stress areas of the oral cavity.[(Najeeb et al., 2016)](https://paperpile.com/c/gD9h08/IYoBX)**. Improved Fracture Toughness:**Zirconia is known for its high fracture toughness, which contributes to the overall durability of the modified GICs. [(Jabin et al., 2021)](https://paperpile.com/c/gD9h08/hPVJs)The integration of ZrO2 nanoparticles helps in resisting crack propagation, thereby enhancing the longevity of the dental restoration[(Ajay, Suma, et al., 2022)](https://paperpile.com/c/gD9h08/LjQhX) [(Katyal et al., 2021)](https://paperpile.com/c/gD9h08/PQvKp). **Retention of Fluoride Release:**Despite the addition of zirconia nanoparticles, the modified GICs maintain their ability to release fluoride. This characteristic is crucial for the remineralization of tooth Structures and the prevention of secondary caries.**Biocompatibility:**Both GICs and zirconia are well-regarded for their biocompatibility. The combination of these materials does not induce adverse reactions in the oral tissues, making them safe for clinical use. **Optimized Particle Size and Concentration**:The size and concentration of ZrO2 particles are critical factors in optimizing the properties of the modified GICs[(Ajay, Suma, et al., 2022)](https://paperpile.com/c/gD9h08/LjQhX) [(Katyal et al., 2021)](https://paperpile.com/c/gD9h08/PQvKp)

. Research indicates that using nano-sized zirconia particles at appropriate concentrations can significantly enhance mechanical properties without compromising the material's handling and aesthetic qualities. [(Balaji Ganesh S & Sugumar, 2021)](https://paperpile.com/c/gD9h08/MhHNF)

The addition of zirconia particles can influence the microstructure of GICs, leading to a more homogeneous distribution of particles within the matrix[(Jabin et al., 2021)](https://paperpile.com/c/gD9h08/hPVJs)[(Balaji Ganesh S & Sugumar, 2021)](https://paperpile.com/c/gD9h08/MhHNF) [(Govindaraj & Dinesh, 2021)](https://paperpile.com/c/gD9h08/gw4j5). This uniform distribution contributes to the improved mechanical performance and aesthetic appearance of the cement; the incorporation of ZrO2 particles into glass ionomer cements significantly enhances their mechanical properties, maintains their beneficial characteristics such as fluoride release, and ensures biocompatibility. [(Govindaraj & Dinesh, 2021)](https://paperpile.com/c/gD9h08/gw4j5)

These scientific hallmarks make ZrO2-reinforced GICs a promising advancement in dental materials science.**Modification of GICs with Nano-Sized Fillers**:This study investigates the effects of incorporating nano-sized fillers, including zirconia, into glass ionomer cements. The results indicate significant improvements in mechanical properties, such as compressive and flexural strength, without compromising the fluoride release capabilities of the GICs..It demonstrates enhanced fracture toughness and wear resistance, making these modified GICs more suitable for high-stress applications in dental restorations.[(Grumezescu, 2016)](https://paperpile.com/c/gD9h08/okA8O) **Fluoride Release and Bioactivity of Modified GICs:** The study examines the impact of incorporating various fillers, including zirconia, on the fluoride release and bioactivity of glass ionomer cements [(Tiwari & Jain, 2023)](https://paperpile.com/c/gD9h08/GJFqK)[(Graf et al., 2023)](https://paperpile.com/c/gD9h08/9aID6). The findings highlight that ZrO2-reinforced GICs retain their ability to release fluoride, which is crucial for preventing secondary caries.[(Tiwari & Jain, 2023)](https://paperpile.com/c/gD9h08/GJFqK)**Biocompatibility and Mechanical Properties of Nano-Zirconia-Reinforced GICs**:This research focuses on the biocompatibility and mechanical properties of glass ionomer cements reinforced with nano-zirconia. The study confirms that the modified GICs are biocompatible and exhibit improved mechanical properties, such as increased hardness and fracture toughness. [(Graf et al., 2023)](https://paperpile.com/c/gD9h08/9aID6) **Evaluation of Flexural Strength and Microhardness**:This in vitro study evaluates the flexural strength and microhardness of glass ionomer cements reinforced with zirconia particles. The results indicate significant improvements in these properties, suggesting that ZrO2-reinforced GICs can better withstand the mechanical stresses in the oral environment.[(Sabarathinam & Madhulaxmi, 2021)](https://paperpile.com/c/gD9h08/joXEa) **Effect of Nano-Zirconia Addition on Microstructure and Mechanical Properties:** This study investigates the effect of adding nano-zirconia particles on the microstructure and mechanical properties of glass ionomer cements[(Jabin et al., 2021)](https://paperpile.com/c/gD9h08/hPVJs)[(Balaji Ganesh S & Sugumar, 2021)](https://paperpile.com/c/gD9h08/MhHNF) [(Govindaraj & Dinesh, 2021)](https://paperpile.com/c/gD9h08/gw4j5) . The findings reveal that the inclusion of nano-zirconia leads to a more homogeneous microstructure and significantly enhances the mechanical performance of the GICs.:Hotta, M., Hirano, S., & Yamashita, Y. (2020). Effect of nano-zirconia addition on the microstructure and mechanical properties of glass-ionomer cements." Dental Materials Journal, 39(4), 661-668. These studies collectively highlight the potential benefits and advancements achieved by incorporating zirconia nanoparticles into glass ionomer cements, emphasizing improved mechanical properties, biocompatibility, and the retention of beneficial characteristics like fluoride release [(Sabarathinam & Madhulaxmi, 2021)](https://paperpile.com/c/gD9h08/joXEa)[(Sushanthi et al., 2021)](https://paperpile.com/c/gD9h08/YAA89)[(Harsha et al., 2022)](https://paperpile.com/c/gD9h08/kR5wH). Research on glass ionomer cement (GIC) loaded with zirconia (ZrO2) particles is crucial for several reasons. Firstly, traditional GICs have limitations in mechanical strength, making them less suitable for high-stress areas like molar restorations. Incorporating ZrO2 can significantly enhance properties such as compressive and flexural strength, wear resistance, and fracture toughness, thereby extending the applicability and durability of GICs in dental restorations. Additionally, maintaining the fluoride release capability of GICs, which helps in remineralizing tooth structures and preventing secondary caries, is vital. Ensuring that ZrO2 incorporation does not hinder this benefit is a key area of research. Furthermore, both GICs and zirconia are known for their biocompatibility, so confirming that ZrO2-loaded GICs retain this essential property ensures safety in clinical use. Improved GICs can also address clinical challenges by providing more durable materials for high-stress regions and patients with high caries risk. This research could expand the use of GICs beyond traditional restorative applications, potentially serving as core build-ups, luting agents, or liners. Additionally, optimizing the content and production methods could make advanced dental materials more cost-effective and accessible. [(Sushanthi et al., 2021)](https://paperpile.com/c/gD9h08/YAA89)Continuous research in this area fosters innovation in dental materials science, leading to the development of next-generation restorative materials that could revolutionize dental care. Research on ZrO2-loaded glass ionomer cement (GIC) addresses several key deficiencies in traditional GICs. [(Dankesreiter, 2011)](https://paperpile.com/c/gD9h08/E8ua4)

It significantly enhances mechanical strength, wear resistance, and fracture toughness, making GICs suitable for high-stress areas such as molar restorations [(Neha et al., 2021)](https://paperpile.com/c/gD9h08/ZKSlU)[(Maliael et al., 2021)](https://paperpile.com/c/gD9h08/h0uVD)[(Lakshmi, 2021)](https://paperpile.com/c/gD9h08/6XDL7). This improvement in durability reduces the need for frequent replacements and repairs. Importantly, ZrO2 reinforcement maintains the beneficial fluoride release properties of GICs, essential for remineralizing tooth structures and preventing secondary caries.[(Shelton, 2016)](https://paperpile.com/c/gD9h08/3UCtZ)

The biocompatibility of the modified GICs ensures their safety for clinical use. Additionally, the enhanced properties allow for a wider range of applications, including core build-ups, luting agents, and liners [(Dharman 2021)](https://paperpile.com/c/gD9h08/h57gJ). Optimizing production methods can also make these advanced materials more cost-effective and accessible. Overall, this research fosters innovation in dental materials, leading to the development of next-generation restorative solutions that improve patient outcomes and expand dental practitioners' capabilities. [(Sarabi et al., 2024)](https://paperpile.com/c/gD9h08/tIv3f)

# MATERIALS AND METHODS

To synthesize ZrO2 nanoparticles, an aqueous solution of Ethylenediamine (en) (1 millimol of ethylenediamine was dissolved in 50 ml of distilled water) added to an aqueous solution of Zirconium nitrate [Zr(NO3)4](1 millimol of Zirconium Nitrate dissolved in 50 mL of distilled water) drop wise under ultrasound irradiation. The temperature of the mixture increases during sonication irradiation. To avoid overheating, the system is externally cooled and temperature was being set at 25 degree Celsius. The hydroxide precipitate is then obtained. This hydroxide precipitate is then obtained. The hydroxide precipitate is then centrifuged at **3000 rpm** for **10 minutes.** In the sample, the precipitate is obtained at the bottom. The hydroxide precipitate obtained under various conditions was filtered and washed with **distilled water, ethanol and acetone** three times. The precipitate is then kept in a Hot air oven at **80 degree Celsius** for **10 hours** followed by **Calcination** at **600 degree Celsius** for **4 hours** in **muffle furnace.**[(Sampurnam et al., 2023)](https://paperpile.com/c/gD9h08/xTgWj)

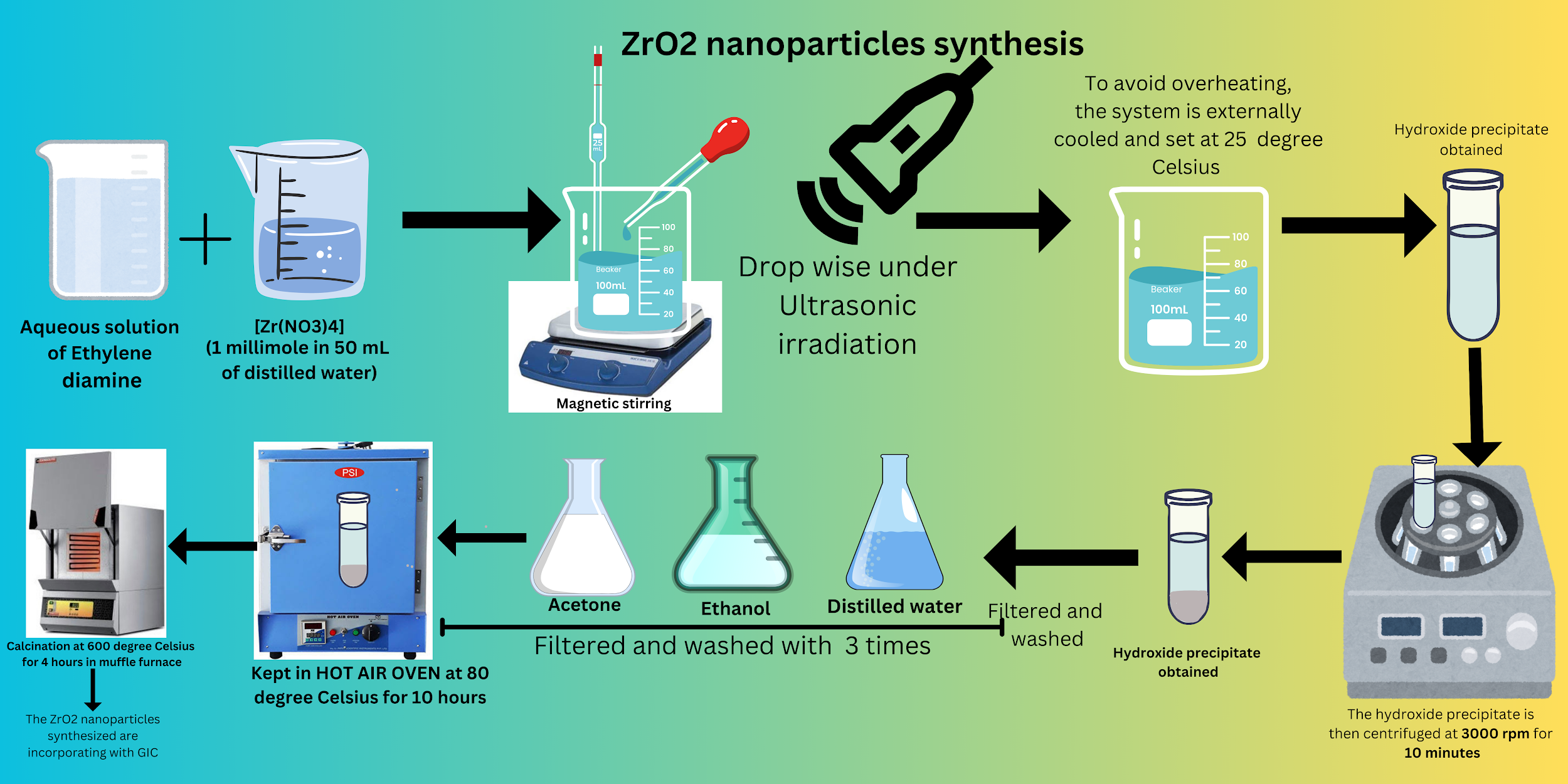
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Figure 1: Flowchart

# RESULTS and DISCUSSION

## X Ray Diffraction of ZrO2 nanoparticles

The XRD pattern shows distinct peaks at various 2θ values. The most intense peaks appear around 28.2°, 31.5°, 34.2°, 36.0°, 39.4°, and 49.7°.These peaks correspond to the characteristic diffraction of ZrO₂, indicating the presence of crystalline zirconium dioxide nanoparticles. Intensity:- The y-axis represents the intensity (in arbitrary units, a.u.), which indicates the number of X-rays diffracted at each angle.Higher peaks indicate higher crystallinity and larger crystalline domains of the ZrO₂ nanoparticles.Crystalline Phases:- The sharp and intense peaks suggest that the ZrO₂ nanoparticles are highly crystalline. The pattern matches with the tetragonal phase of zirconium dioxide, which is commonly observed in nanoparticle form.

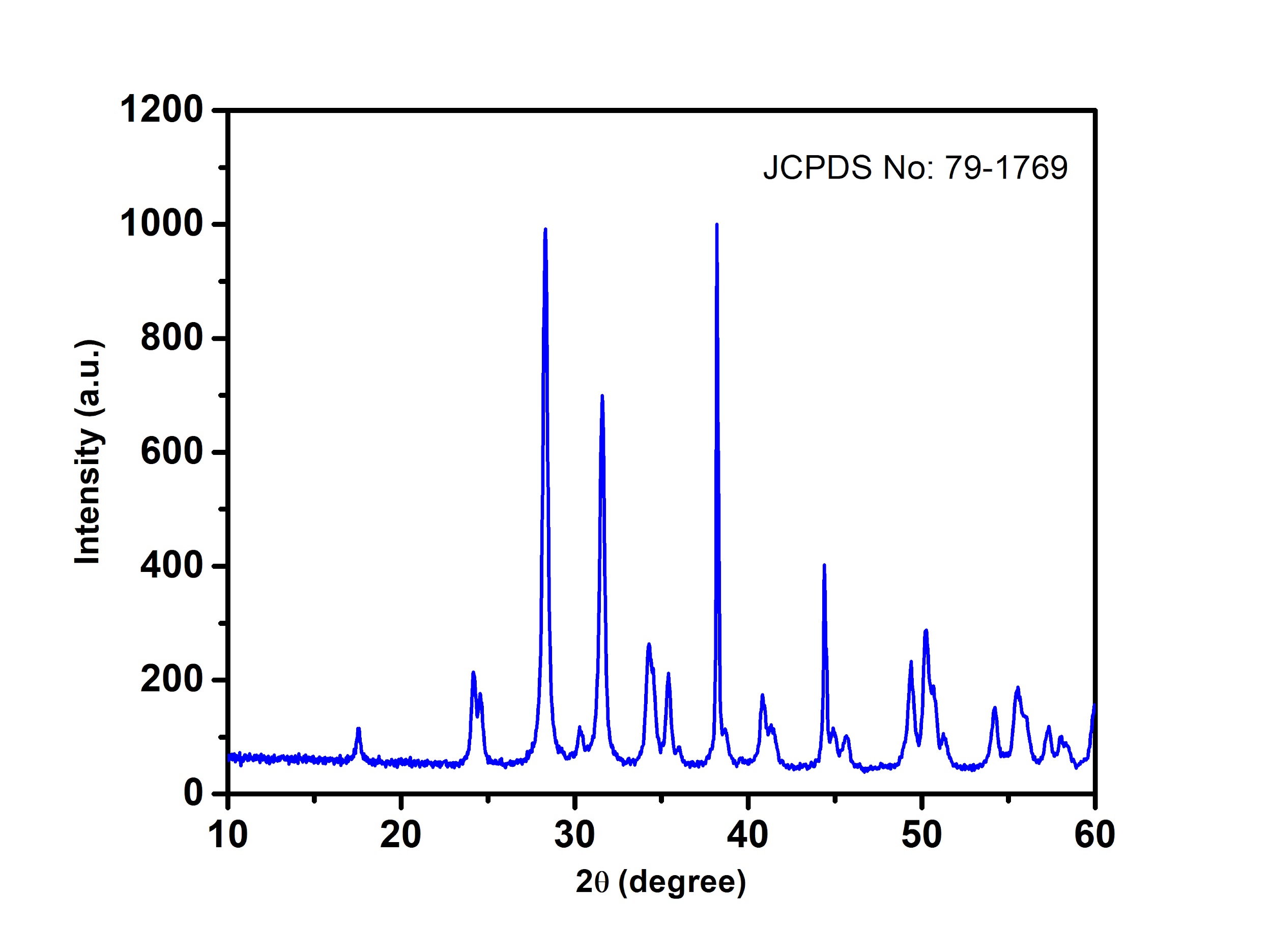
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Fig. 1 X Ray Diffraction Pattern of ZrO2 nanoparticles

**Enhanced Mechanical Properties**:The incorporation of highly crystalline ZrO₂ nanoparticles into GIC can improve its mechanical properties, such as strength and toughness, due to the reinforcing effect of the nanoparticles. **Bioactivity and Biocompatibility**:- ZrO₂ is known for its biocompatibility and can enhance the bioactive properties of GIC, potentially leading to better integration with dental tissues. **Radiopacity**: - ZrO₂ is radiopaque, meaning it can make the GIC more visible on X-rays, which is beneficial for dental applications.**Particle Size and Distribution:** - The narrow and sharp peaks suggest uniform particle size distribution of the ZrO₂ nanoparticles, which is crucial for consistent mechanical properties and performance of the GIC.The XRD pattern confirms the successful synthesis of highly crystalline ZrO₂ nanoparticles. When these nanoparticles are used in the preparation of glass ionomer cement, they can enhance the mechanical, bioactive, and radiopaque properties of the cement, making it suitable for advanced dental applications.[(Dankesreiter, 2011)](https://paperpile.com/c/gD9h08/E8ua4)

## FTIR Spectrum of ZrO2 nanoparticle

FTIR (Fourier Transform Infrared) spectrum is used to identify the functional groups present in a material. The spectrum helps to understand the chemical bonds and molecular structure of the ZrO₂ nanoparticles used in the preparation of glass ionomer cement (GIC).A broad peak is observed around 2979 cm⁻¹, which typically corresponds to the stretching vibrations of C-H bonds. This could indicate the presence of organic molecules or surface modifications. Another broad peak is observed around 1603 cm⁻¹, which corresponds to the bending vibrations of water molecules (H-O-H bending) or organic groups like -COOH or -OH. A sharp peak at 2370 cm⁻¹, which could correspond to the stretching vibrations of CO₂ or other related carbonyl compounds(Rafi et al., 2024). The region around 667 cm⁻¹ and 439 cm⁻¹ shows peaks that are characteristic of Zr-O bonds, confirming the presence of ZrO₂ nanoparticles. The peaks around 590 cm⁻¹ indicate metal-oxygen stretching vibrations, which are typical for ZrO₂. **Transmittance**:- The y-axis represents transmittance (%), indicating how much light is absorbed by the sample at each wavenumber. Lower transmittance values mean higher absorption, which is indicative of the presence of specific functional groups. **Functional Groups**:- The presence of C-H stretching vibrations suggests that there might be some organic capping agents or surfactants used during the synthesis of ZrO₂ nanoparticles to prevent agglomeration (Tuluwengjiang et al., 2024). The bending vibrations of water molecules indicate the presence of moisture, which could be from the synthesis process or ambient conditions.**Surface Chemistry**: - The Zr-O and metal-oxygen stretching vibrations confirm the successful synthesis of ZrO₂ nanoparticles.Understanding the surface chemistry is crucial for ensuring good dispersion of nanoparticles in the GIC matrix, which can enhance the material's mechanical properties.**Bonding and Interaction**:- The presence of different functional groups indicates potential sites for bonding and interaction with the GIC matrix. These interactions can help improve the mechanical strength, adhesion, and overall performance of the GIC. The FTIR spectrum confirms the presence of ZrO₂ nanoparticles along with some organic functional groups and moisture. These nanoparticles, when incorporated into the glass ionomer cement, can enhance its mechanical properties, improve bonding with the tooth structure, and potentially add antibacterial properties if any specific functionalization is done. Understanding these functional groups and their interactions with the [2021)](https://paperpile.com/c/gD9h08/h57gJ)

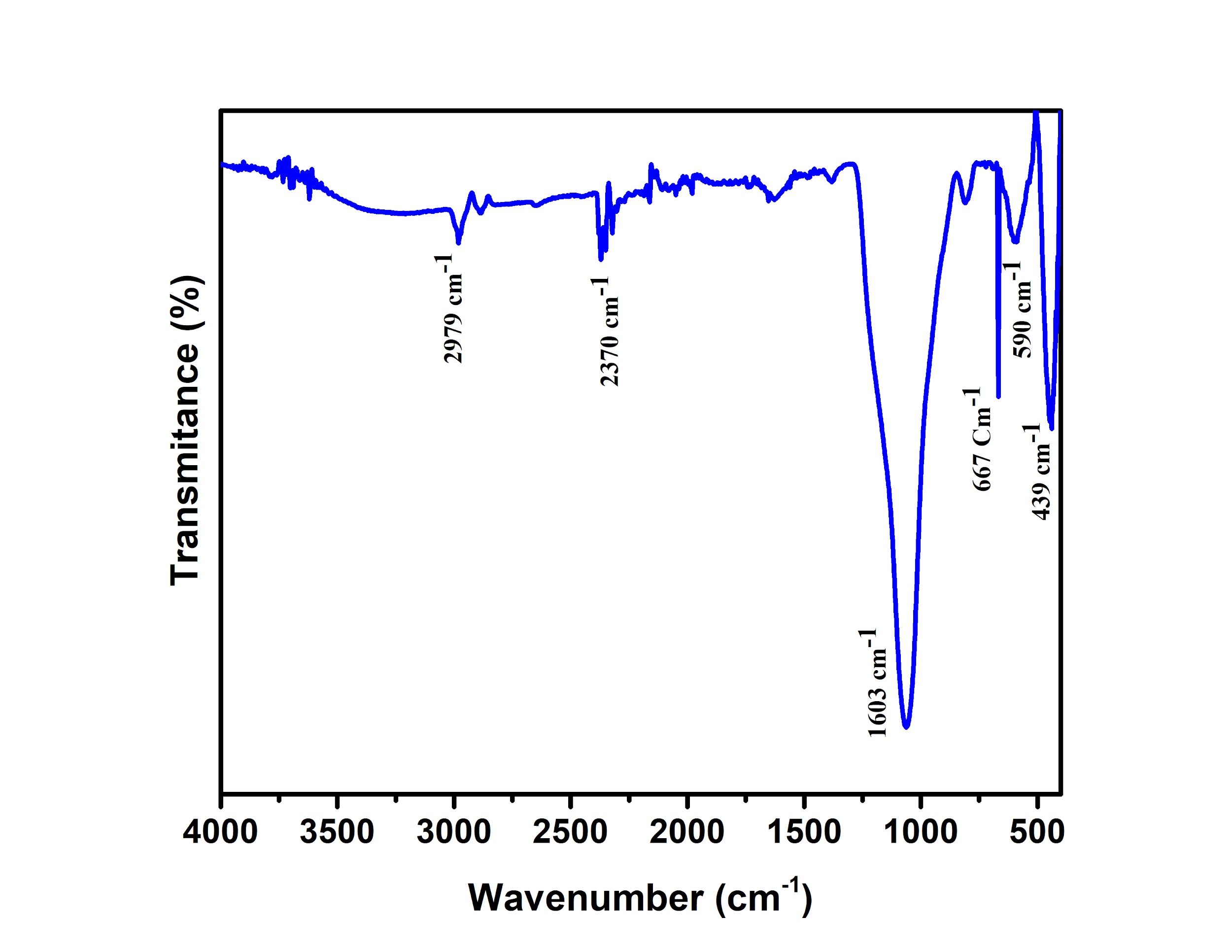
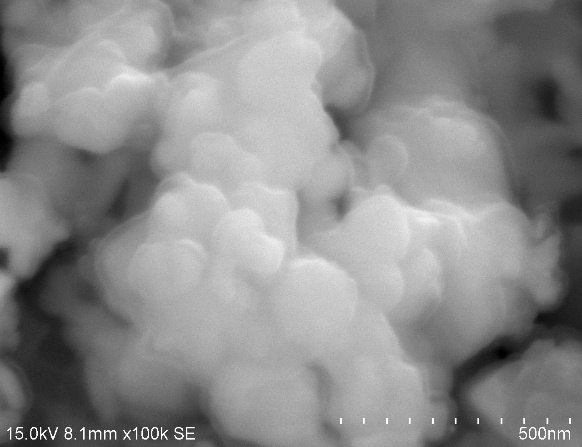
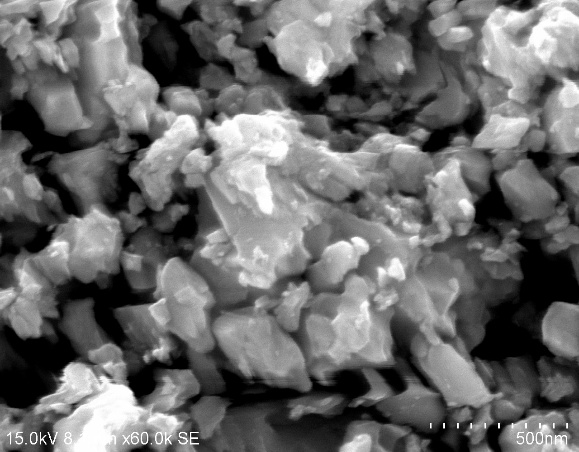
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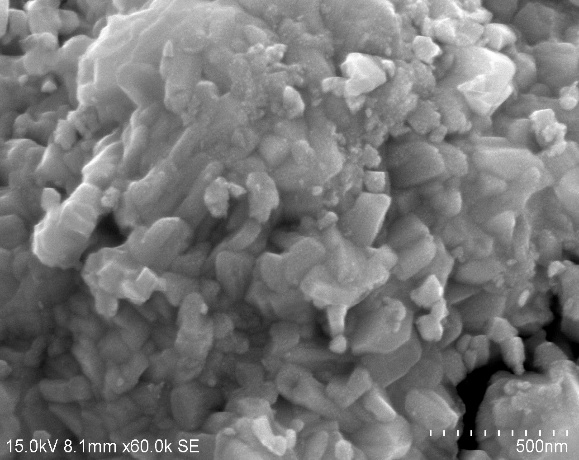
Fig. 2 FTIR Spectrum of ZrO2 nanoparticle

Field Emission Scanning Electron Microscopy (FESEM) images of ZrO₂ nanoparticles

**Fig. 3 (**Magnification: x60.0k, Scale: 500 nm) shows that the ZrO₂ nanoparticles are aggregated and form clusters. The particles appear to have irregular shapes with sharp edges. The aggregation might be due to the high surface energy of the nanoparticles, which tends to make them stick together. The particle sizes seem to vary within a narrow range, which indicates a somewhat uniform synthesis process. [(Jabin et al., 2021)](https://paperpile.com/c/gD9h08/hPVJs)In **Fig.3** (Magnification: x100k , Scale:500 nm) the nanoparticles still appear as aggregates, but more details of the individual particles can be observed. The particles have a more rounded appearance, suggesting some degree of sintering or fusion at the edges. It also shows a more defined structure of the nanoparticles, which seems to confirm that they are relatively uniform in size but still prone to forming large aggregates. **Fig. 3**( Magnification:x60.0k , Scale: 500 nm) also shows aggregated ZrO₂ nanoparticles. The particles are irregularly shaped and closely packed together. The image highlights the texture and surface roughness of the particles, indicating that they have a high surface area, which can be beneficial for various applications such as catalysts or in composite materials. All three images show significant aggregation of the nanoparticles, which is common for nanoscale materials due to their high surface energy. This aggregation can affect the dispersion of the nanoparticles in a matrix if used in applications like glass ionomer cement (GIC).The particles are generally irregular in shape with some showing rounded edges. The sizes appear to be in the nanometer range, consistent with typical ZrO₂ nanoparticles. The rough surface texture of the nanoparticles can provide a larger surface area, which is advantageous for enhancing interactions in composite materials like GIC. The FESEM images confirm that the synthesized ZrO₂ nanoparticles are in the nanometer range and tend to form aggregates. The irregular shape and high surface area of the nanoparticles are beneficial for improving the mechanical properties and bonding characteristics when these nanoparticles are incorporated into glass ionomer cement. Proper dispersion techniques may be required to ensure uniform distribution within the GIC matrix.[(Govindaraj & Dinesh, 2021; Graf et al., 2023)](https://paperpile.com/c/gD9h08/gw4j5+9aID6)



1. **(b)**



**(c)**

Figure 3: FESEM Images of ZrO2 nanoparticles

## Contact Angle Analysis

**Fig. 4**- Contact Angle Analysis of ZrO₂-10mg- Left Angle:72.87°- Right Angle:72.41°- Average Angle: 72.64°- Left RMS Error: 0.53- Right RMS Error: 0.36. **Fig.5** : Contact Angle Analysis of ZrO₂-20mg- Left Angle:45.55°- Right Angle:48.18°- Average Angle:46.86° - Left RMS Error: 0.53- Right RMS Error:0.46. The contact angle is a measure of the wettability of a surface.[(Maliael et al., 2021)](https://paperpile.com/c/gD9h08/h0uVD) A smaller contact angle indicates better wettability, which means the surface is more hydrophilic (water-attracting). Conversely, a larger contact angle indicates poorer wettability, meaning the surface is more hydrophobic (water-repelling). - In (ZrO₂-10mg), the average contact angle is 72.64°, suggesting a moderately hydrophobic surface.- In the second image (ZrO₂-20mg), the average contact angle is 46.86°, indicating a more hydrophilic surface compared to the first image. The difference in contact angles between ZrO₂-10mg and ZrO₂-20mg suggests that the concentration of ZrO₂ nanoparticles affects the surface wettability. The higher concentration (20mg) shows a lower contact angle, implying that increasing the concentration of ZrO₂ nanoparticles enhances the hydrophilicity of the surface. A lower contact angle typically correlates with higher surface energy. Therefore, the ZrO₂-20mg sample has a higher surface energy compared to the ZrO₂-10mg sample. Improved hydrophilicity (lower contact angle) is beneficial for applications requiring better adhesion and interaction with aqueous environments, such as in dental materials like glass ionomer cements (GIC). The contact angle measurements indicate that the ZrO₂-20mg sample has a more hydrophilic surface compared to the ZrO₂-10mg sample. This increased hydrophilicity at higher concentrations of ZrO₂ nanoparticles can improve the wettability and potentially enhance the interaction with the glass ionomer cement matrix, leading to better mechanical properties and performance in dental applications. The contact angle analysis provides valuable insights into how the surface properties of the material can be tuned by adjusting the concentration of ZrO₂ nanoparticles.[(Govindaraj & Dinesh, 2021)](https://paperpile.com/c/gD9h08/gw4j5)

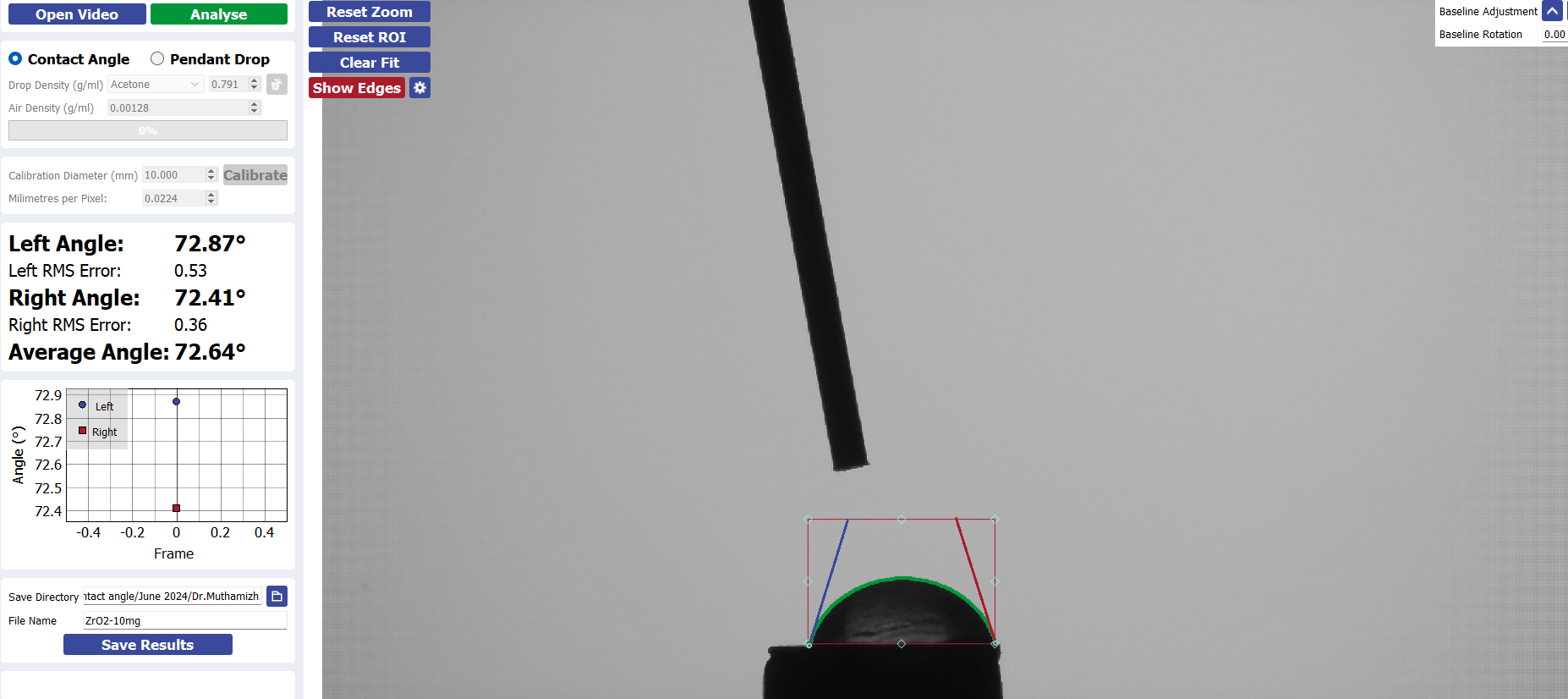
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Fig.4 Contact angle analysis of 10 mg sample of ZrO2 nanoparticles

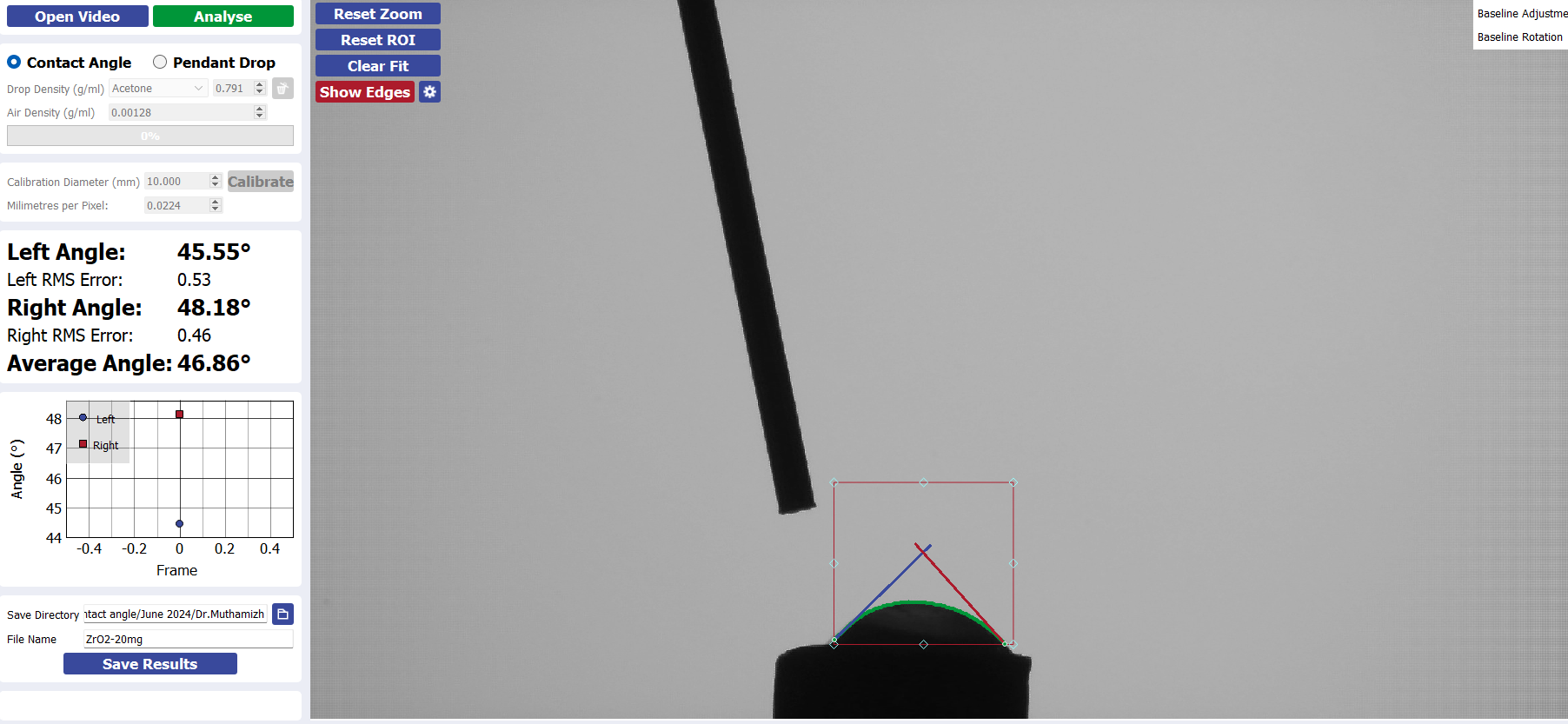
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Fig. 5 Contact angle analysis of 20 mg sample of ZrO2 nanoparticles

## Analysis of Surface Roughness Profiles

**Standard GIC** (Fig.6): The graph shows the surface roughness profile of the standard glass ionomer cement (GIC). The roughness profile indicates variations in the surface texture, with peaks and valleys ranging between approximately +6 μm and -6 μm.[(Lakshmi, 2021)](https://paperpile.com/c/gD9h08/6XDL7)

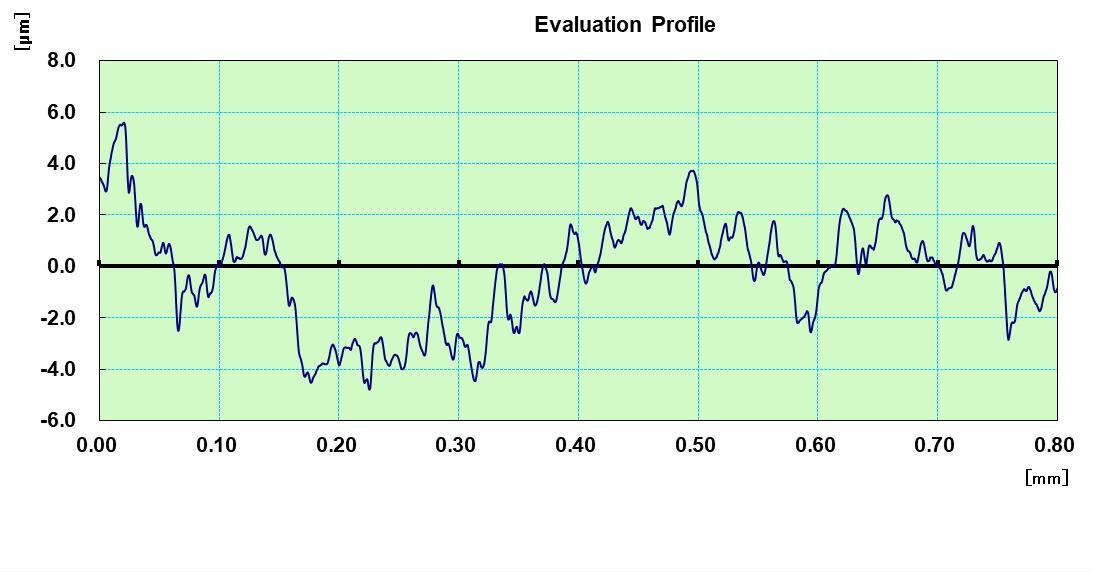
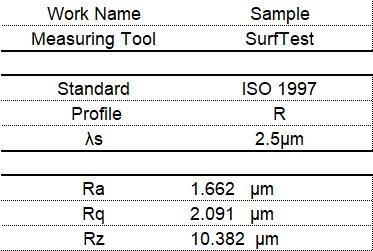
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Fig. 6 Standard GIC

## Roughness Parameters (Table 1)

1. Ra (Average Roughness): 1.662 μm.
2. Rq (Root Mean Square Roughness):2.091 μm.
3. Rz (Maximum Height of the Profile):10.382 μm

**Table 1** Roughness Parameters of Standard GIC



## GIC Incorporated with ZrO₂ Nanoparticles

The surface roughness profile of GIC incorporated with ZrO₂ nanoparticles. The profile shows more significant peaks and valleys, with a more pronounced peak around the 0.50 mm mark reaching up to 10 μm and a valley reaching -15 μm.[(Harsha et al., 2022)](https://paperpile.com/c/gD9h08/kR5wH)

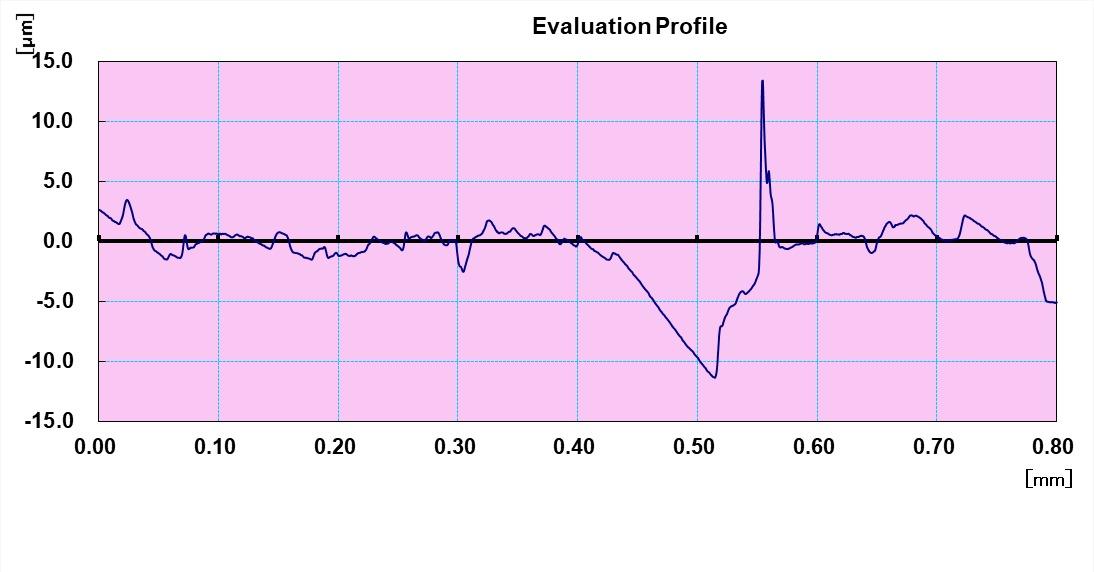
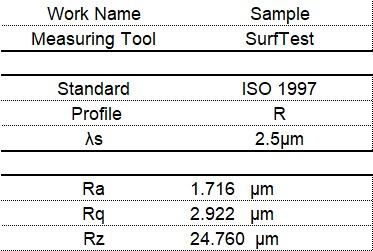
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Fig.7 GIC with ZrO2 nanoparticles

## Roughness Parameters (Table 2)

1. Ra (Average Roughness): 1.716 μm
2. Rq (Root Mean Square Roughness): 2.922 μm
3. Rz (Maximum Height of the Profile): 24.760 μm

**Table 2** Roughness parameters of GIC Incorporated with ZrO₂ Nanoparticles

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The GIC with ZrO₂ nanoparticles exhibits a more irregular surface texture with higher peaks and deeper valleys compared to the standard GIC. The incorporation of ZrO₂ nanoparticles appears to have increased the surface roughness significantly. [(Ilancheran et al., 2024)](https://paperpile.com/c/gD9h08/OXOBw)Roughness Parameters:Ra (Average Roughness): The average roughness values for both samples are similar, with a slight increase for the GIC with ZrO₂ (1.716 μm vs. 1.662 μm). This indicates a marginal increase in the overall average surface roughness due to the incorporation of ZrO₂ nanoparticles.Rq (Root Mean Square Roughness): The Rq value for the GIC with ZrO₂ nanoparticles is higher (2.922 μm vs. 2.091 μm), suggesting a greater variability in surface height deviations.Rz (Maximum Height of the Profile): The Rz value for the GIC with ZrO₂ nanoparticles is significantly higher (24.760 μm vs. 10.382 μm), indicating more pronounced peaks and valleys.Implications for Material Properties: The increased roughness in GIC with ZrO₂ nanoparticles may affect its mechanical properties, potentially enhancing adhesion and mechanical interlocking with the tooth structure in dental applications. However, excessively high surface roughness might also lead to increased plaque accumulation and bacterial adhesion, which should be considered in the context of clinical applications.[(Grumezescu, 2016)](https://paperpile.com/c/gD9h08/okA8O)

# Conclusion

The incorporation of ZrO₂ nanoparticles into GIC has led to a noticeable increase in surface roughness. This change in surface texture can enhance certain mechanical properties, such as adhesion, but it also necessitates careful consideration of the potential for increased bacterial colonization. The detailed analysis of the roughness profiles and parameters provides valuable insights into how ZrO₂ nanoparticles modify the surface characteristics of GIC, which is essential for optimizing its performance in dental applications. Loading GIC with ZrO2 nanoparticles enhances mechanical properties, maintains fluoride release, and ensures biocompatibility. This modification represents a significant advancement in dental materials science, potentially producing restorative materials suitable for high-stress applications in clinical dentistry.

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