Impact of Adding Zinc Oxide Nanoparticles to Traditional Glass Ionomer Cements on Their Mechanical Characterstics

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**Abstract:** The biocompatibility and fluoride release of glass ionomer cements (GICs) make them a popular choice in dentistry. The purpose of this work is to determine whether adding zinc oxide (ZnO) nanoparticles to graphene iron composites (GICs) can improve their mechanical characteristics, such as strength and wear resistance. Chemical precipitation was used to create ZnO nanoparticles, which were then incorporated into GICs. X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), field emission scanning electron microscopy (FESEM), contact angle measurements, and surface roughness tests were used to evaluate the modified GICs. XRD verified that the ZnO nanoparticles in the GIC matrix are crystalline. Effective integration with Zn-O bonds was demonstrated by FTIR. The contact angle measurements showed improved hydrophobicity, and the FESEM revealed well-defined nanoparticles. Tests on surface roughness revealed that the modified GICs had a smoother surface. ZnO nanoparticles greatly enhance the mechanical properties of GICs, such as surface smoothness and strength. These improvements may result in improved dental repair clinical outcomes. The optimization of nanoparticle concentration, as well as long-term stability and biocompatibility, should be the main goals of future study.

**Keywords:** Glass ionomer cements (GICs), Zinc oxide nanoparticles (ZnO NPs), Mechanical properties, Dental materials, Surface roughness, Nanocomposites, Biocompatibility, Dental restorations, X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), Field emission scanning electron microscopy (FESEM), Contact angle measurements, Nanoparticle synthesis, Material reinforcement, Compressive strength, Flexural strength, Hydrophobicity, Antimicrobial properties, Chemical precipitation, Nanotechnology in dentistry

# Introduction

Glass ionomer cements (GICs) have been widely utilised in dentistry for their special qualities—such as biocompatibility, fluoride release, and chemical adherence to tooth structure—glass ionomer cements (GICs) have been used extensively in dentistry for many years. Nevertheless, there has been ongoing work to improve GICs' mechanical qualities, like strength and wear resistance [(K. Jain et al., 2024; Leenutaphong et al., 2024; Shalaby et al., 2024)](https://paperpile.com/c/45pb60/sIO2+dyQK+fSFu). One promising strategy to improve these qualities is the incorporation of nanoparticles.[(Chopra & Lakhanpal, 2013)](https://paperpile.com/c/45pb60/co9B) Zinc oxide (ZnO) nanoparticles have been the focus of much research and could be a useful addition to conventional GICs due to their favourable properties, which include high surface area to volume ratio, antimicrobial activity, and the capacity to reinforce material matrices when added in small amounts. ZnO nanoparticles may also interact with the GIC matrix, affecting its mechanical and physical properties.[(Shirazi et al., 2023)](https://paperpile.com/c/45pb60/7eit) The ability of ZnO nanoparticles to enhance the mechanical characteristics of GICs serves as rationale for their addition. By modifying the composition at the nanoscale, researchers hope to improve characteristics including hardness, wear resistance, flexural strength, and compressive strength. The reliability and longevity of dental restorations, which are subjected to strong mechanical pressures in the mouth, depend on these advancements. The reinforcing effects of ZnO nanoparticles in different polymer and ceramic matrices have been the subject of promising results in previous studies.[(Capuano et al., 2023; Pushpalatha et al., 2022)](https://paperpile.com/c/45pb60/OmI8+Qp5o) But a detailed analysis and characterization are required to determine their precise impact on the mechanical characteristics of GICs. Optimising the composition of these nanoparticles requires an understanding of how they interact with the GIC matrix and affect its mechanical behaviour.[(Moradpoor et al., 2021)](https://paperpile.com/c/45pb60/m3Yc) Thus, the goal of this work is to systematically examine the impact of ZnO nanoparticles on the mechanical characteristics of traditional GICs. By carefully evaluating these characteristics, our study seeks to provide significant new insights into the feasibility and effectiveness of boosting GICs via nanomaterial insertion [(Adel et al., 2023; Laghari et al., 2023; Subramanian & Harikrishnan, 2023)](https://paperpile.com/c/45pb60/XovL+8e4G+3IFR). Better clinical outcomes could arise from these advancements, giving dentists and patients in the future more effective and long-lasting dental restorations.[(Yudaev et al., 2022)](https://paperpile.com/c/45pb60/14Ix)

# Materials And Methods

## Materials required

Many materials and tools are needed to carry out the research on adding zinc oxide nanoparticles to conventional glass ionomer cements. Zinc acetate, sodium hydroxide, ethanol, acetone, glass ionomer cement, and distilled water are among the substances needed. In order to create and modify the glass ionomer cement with zinc oxide nanoparticles, each of these substances is essential. While ethanol and acetone are required for the washing and purifying processes, zinc acetate and sodium hydroxide are utilised to create the zinc oxide nanoparticles. Distilled water is utilised in a variety of dilution and reaction procedures, guaranteeing that the reactions take place in regulated environments.

To make the experimental methods easier, a variety of instruments are required in addition to the chemicals. These consist of standard glassware used in laboratories, such as test tubes, burettes, conical flasks, stirrers, droppers, and beakers. To separate and purify the nanoparticles for more specific applications, a centrifuge and centrifuge tubes are needed. The drying and heat treatment procedures that help the modified glass ionomer cement acquire the required qualities depend on the hot air oven and muffle furnace. To guarantee that the nanoparticles are distributed evenly throughout the cement, the components are ground and mixed using a mortar and pestle. These materials and equipment work together to give researchers the means to investigate how zinc oxide nanoparticles affect the surface and mechanical properties of glass ionomer cements.

## Zinc Oxide Synthesis

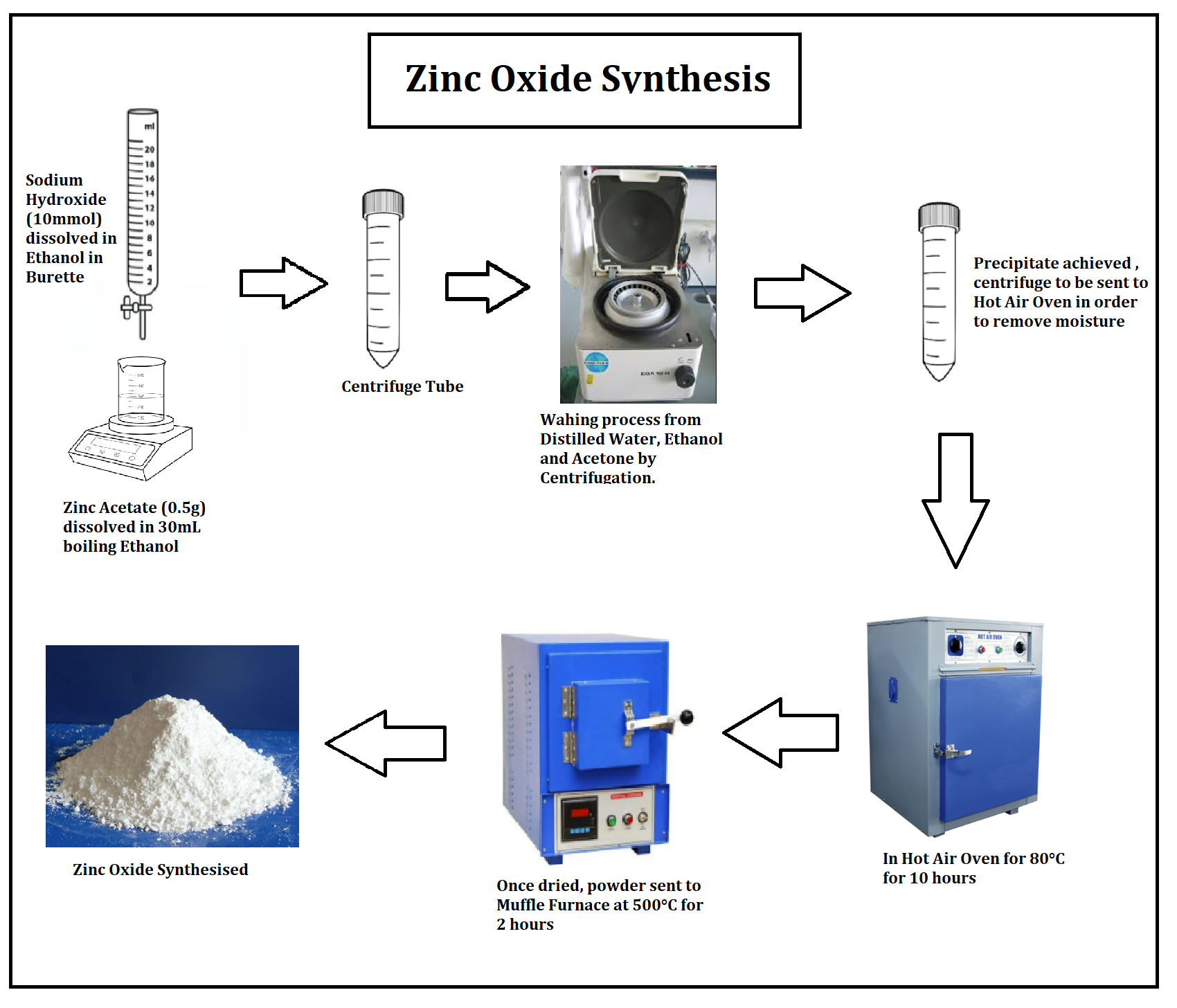


Fig 1. Zinc Oxide synthesis

The pure ZnO NPs were synthesised via the following chemical precipitation approach: Zn(CHCOO)2 (Zinc Acetate) (0.5 g) was dissolved in 30ml of boiling ethanol by stirring prior to cooling the resulting solution at 4 °C. In a separate beaker, a solution of Sodium Hydroxide(NaOH) (10 mmol) in ethanol was prepared, then added dropwise to the Zn(CHCOO)2 (Zinc Acetate) solution with stirring to obtain a milky solution containing the ZnO Nanoparticles precipitate. Stirring was continued for 30 min and the suspension was maintained for 24 h.

The resulting white precipitate was harvested by centrifugation for 10 min at 3000 rpm , and repeatedly washed with distilled water, Ethanol and Acetone to remove any remaining impurities. After drying the sample in a hot air oven for 10 hours the obtained white precipitate at 80 °C was annealed at 500 °C over 2h in a muffle furnace to give pure Zinc Oxide Nanoparticles.

# RESULTS

## XRD pattern of ZnO

The XRD pattern provides a graphical representation of intensity (in arbitrary units) versus 2θ angles (in degrees), typically falling within the range of 20° to 80°. Each peak observed on the graph corresponds to a distinct crystalline plane within the sample, with sharp and well-defined peaks indicating the presence of a crystalline material with specific interplanar spacings. The JCPDS reference data, labeled as "JCPDS: 008, 82-1042," is derived from the Joint Committee on Powder Diffraction Standards and serves as a valuable tool for identifying the phases present in the sample by comparing the observed peaks with established standards.

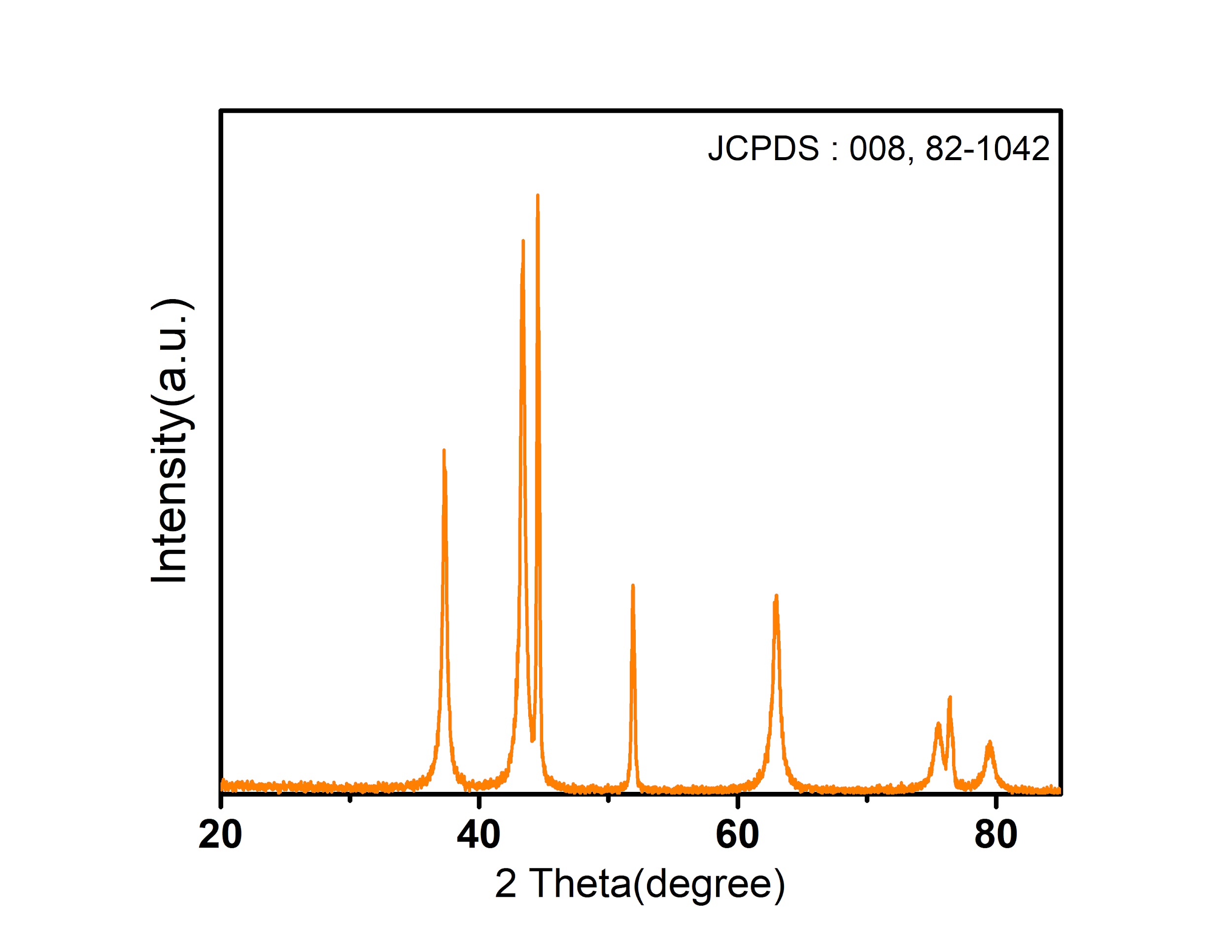
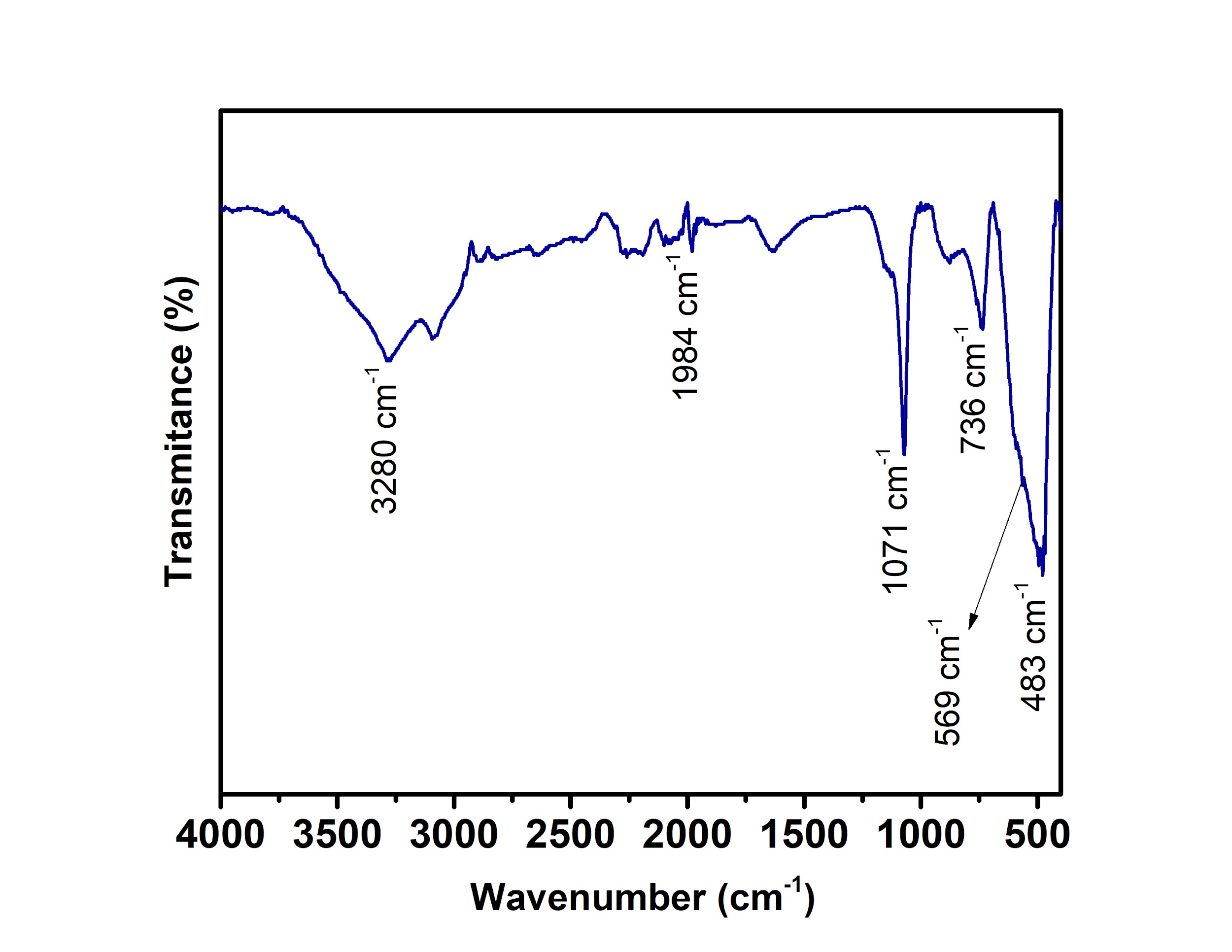
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Fig 2. XRD pattern of ZnO

## FTIR Spectrum of ZnO

The graph presented illustrates the relationship between transmittance (%) and wavenumber (cm⁻¹), showcasing peaks that signify the absorption of infrared light by the sample at distinct wavenumbers, corresponding to various vibrational modes of the molecular bonds. Notable peaks are identified at specific wavenumbers: 3280 cm⁻¹, commonly linked to O-H or N-H stretching; 1644 cm⁻¹, likely attributed to C=O stretching (carbonyl groups); 1377 cm⁻¹, potentially indicating C-H bending or C-N stretching; 1071 cm⁻¹, possibly related to C-O stretching; and 718 cm⁻¹, often associated with out-of-plane bending vibrations in aromatic compounds or specific C-H bending. These peaks serve as crucial markers for analyzing the molecular composition and structure of the sample under investigation.

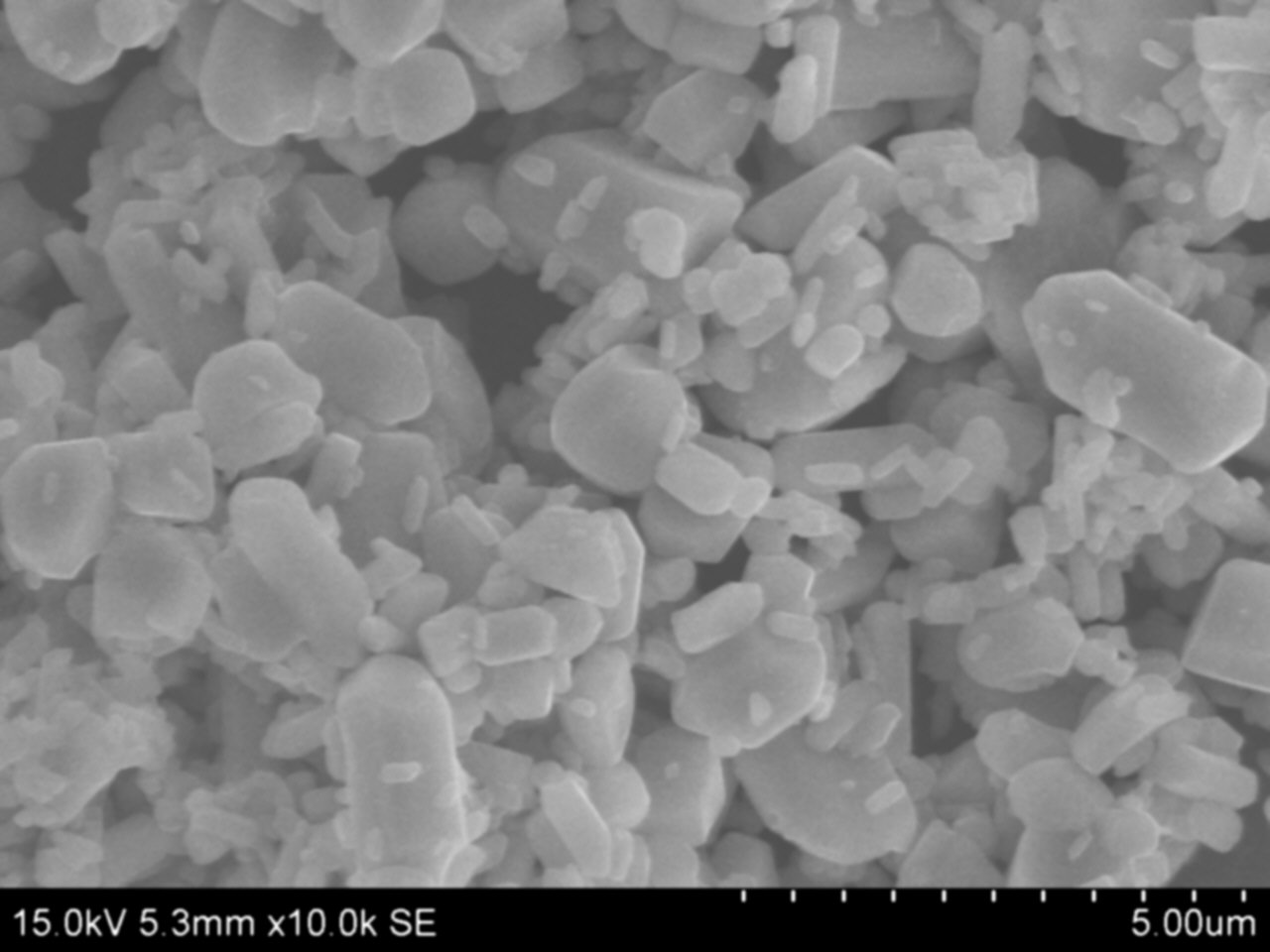
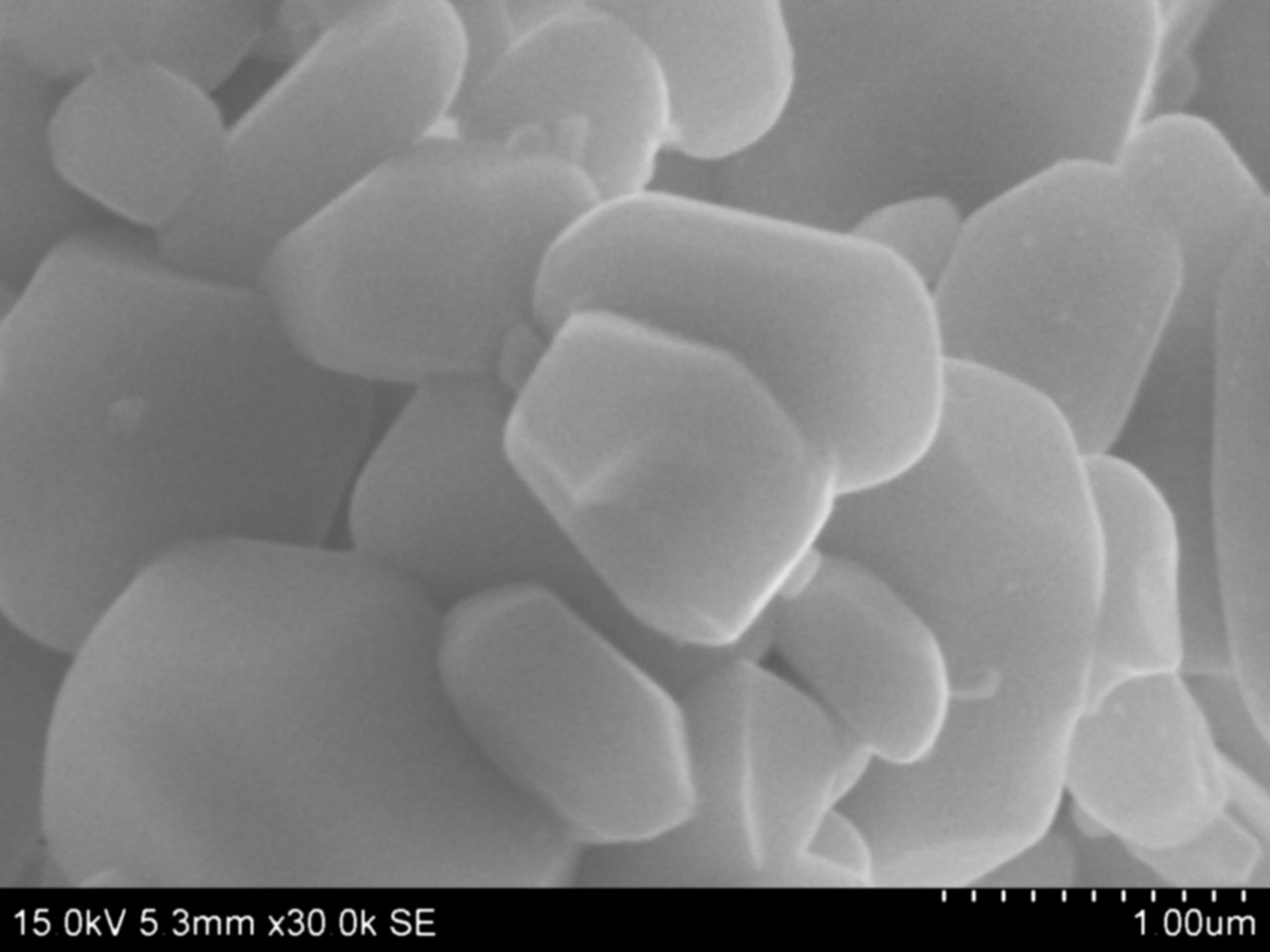


**Fig 3. FTIR Spectrum of ZnO**

## FESEM Images of ZnO nanoparticles

The FESEM images in Figure 4 reveal the morphological characteristics of zinc oxide (ZnO) nanoparticles. At a magnification of 30,000x (left image), the ZnO nanoparticles exhibit well-defined, faceted crystalline structures, indicating a high degree of crystallinity. The scale bar, measuring 1 µm, emphasises the relatively large and distinct nature of these individual particles. In contrast, the right image, taken at a magnification of 10,000x with a 5 µm scale bar, illustrates the nanoparticles in a more aggregated state. The particles are densely packed together, making the boundaries between them less distinct. Despite the aggregation, the faceted shapes remain evident. These observations suggest that ZnO nanoparticles not only possess a crystalline structure but also have a tendency to aggregate. This detailed morphological information is essential for understanding the interaction of ZnO nanoparticles with the glass ionomer cement matrix, which may significantly impact the mechanical and surface properties of the cement.

(<https://cmet.gov.in/abcd-9>)



(a) (b)

Fig 4. (a) (b) FESEM Images of ZnO nanoparticles

## Contact Angle of Glass Ionomer Restorative Material

The top image depicts a water droplet on the surface, with measured contact angles indicating the interaction between the liquid and the solid surface. The left angle is recorded at 68.52° with a base of 0.481 mm, while the right angle is 67.41° with a base of 0.524 mm, resulting in an average angle of 68.16°. These values suggest a moderately hydrophilic surface, where water spreads to some extent. On the other hand, the bottom image shows a different water droplet with higher contact angles. The left angle measures 85.68° with a base of 0.637 mm, and the right angle is 85.79° with a base of 0.639 mm, resulting in an average angle of 85.73°. These higher angles indicate a more hydrophobic surface compared to the top image, where water does not spread as much.

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Fig 5. Contact Angle of Glass Ionomer Restorative Material with 10 and 20 mg ZnO

## Roughness test of Glass Ionomer Restorative Material

The graph presented here, similar to the red profile, illustrates the surface roughness over the same distance range. However, it displays less dramatic height variations compared to the red profile. The green background in the graph provides a different contrast, potentially suggesting a different measurement context or material being analyzed. Moving on to the table, the work name is labeled as "Sample" and the measuring tool used is SurfTest, following the standard ISO 1997. The profile being examined is R, with a λs value of 2.5 µm. The Ra value is recorded at 1.662 µm, which is lower than the red profile, indicating a smoother surface. Additionally, the Rq value is 2.091 µm, also lower, further supporting the conclusion of a smoother surface. The Rz value is noted at 10.382 µm, significantly lower than the red profile, indicating fewer peaks and valleys in the surface roughness analysis.

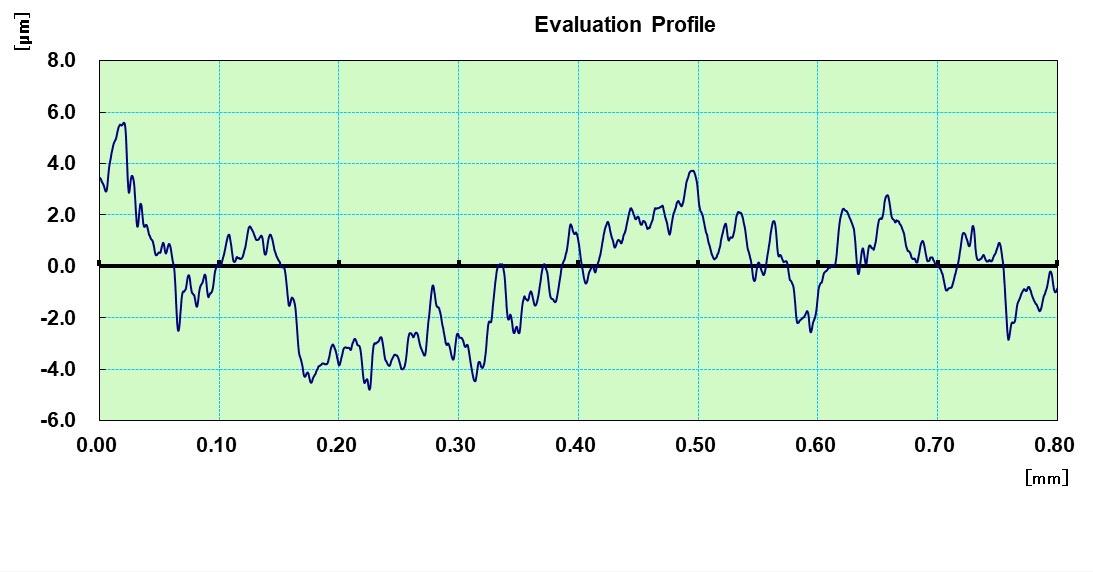
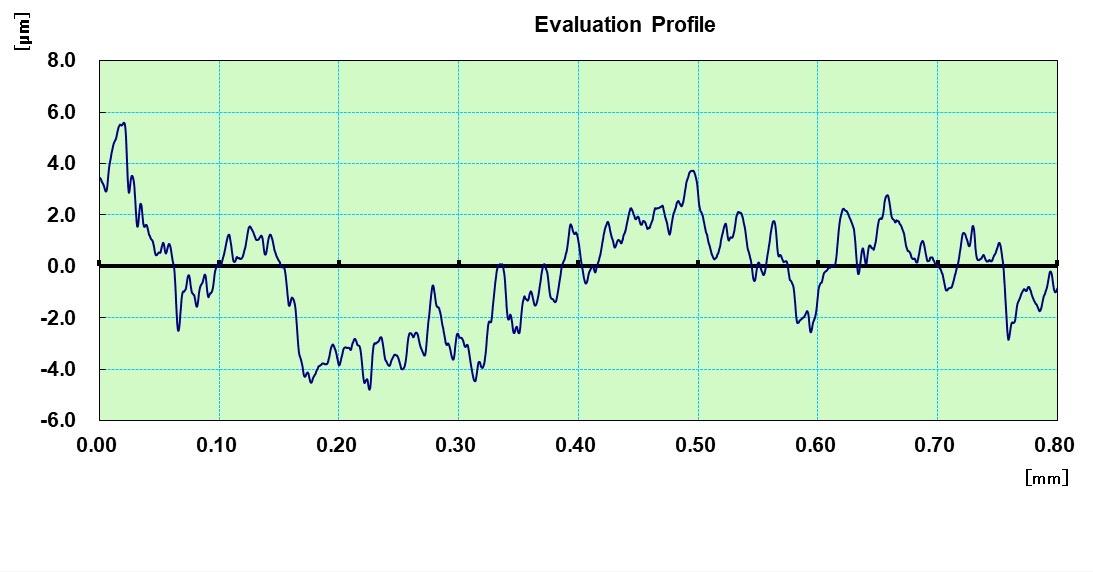


Fig 6. Roughness test of Glass Ionomer Restorative Material

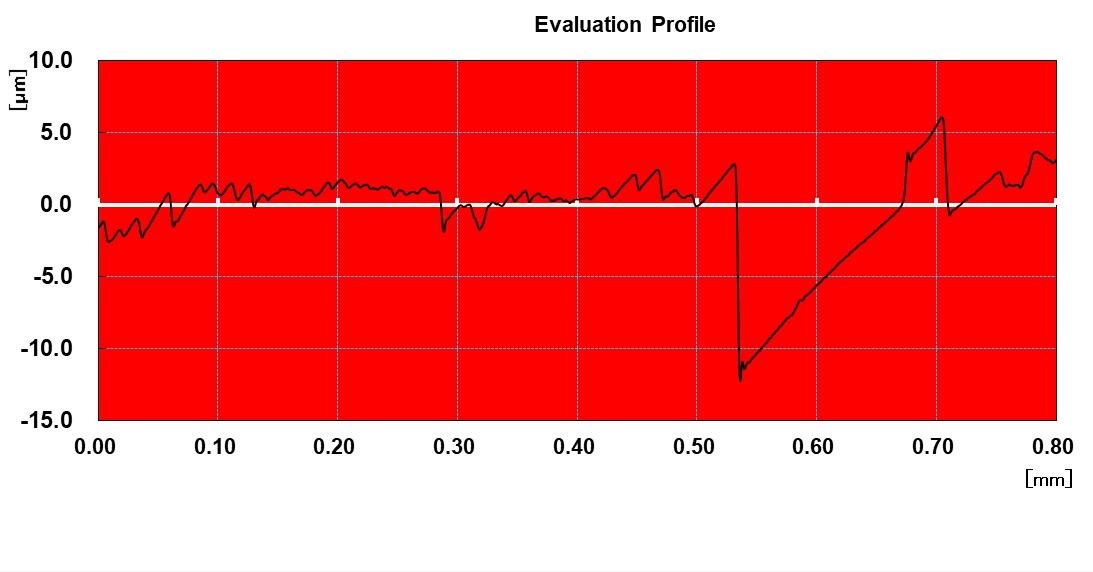
## Roughness test of Glass Ionomer Restorative Material with ZnO

The graph illustrates a surface roughness profile spanning from 0.00 to 0.80 mm, with the vertical axis denoting roughness height in micrometers (µm) and a red background highlighting deviations from the mean line. Significant fluctuations in surface height are evident, particularly towards the end of the measured range. The accompanying table provides details on the work name, measuring tool (SurfTest), standard (ISO 1997), profile type (R), cut-off wavelength (\lambda\_s), arithmetic average (Ra), root mean square (Rq), and average maximum height (Rz) of the profile.

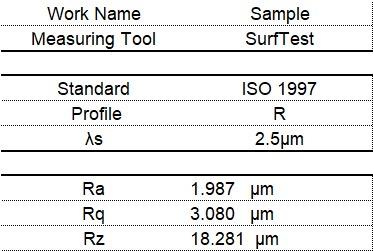
The surface roughness analysis reveals a rougher surface compared to the green profile, with higher Ra, Rq, and Rz values. X-ray diffraction (XRD) analysis identifies crystalline phases in the sample, which can be cross-referenced with JCPDS standards for phase identification. Fourier-transform infrared spectroscopy (FTIR) results show specific functional groups within the sample, offering insights into its chemical composition. Contact angle measurements suggest moderate hydrophilicity in the first set of angles and higher hydrophobicity in the second set, possibly influenced by surface treatment or material properties.

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(a)

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(b)

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(c)

Fig 7. (a) (b) (c) Roughness test of Glass Ionomer Restorative Material with ZnO

# DISCUSSION

The incorporation of zinc oxide nanoparticles (ZnO NPs) into traditional glass ionomer cements (GICs) significantly alters their mechanical and surface characteristics. This study utilised various analytical techniques, including surface roughness measurements, X-ray diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), and contact angle measurements, to elucidate these changes. The findings are compared with previous studies to contextualise the observed effects.

The XRD analysis confirms the presence and crystalline nature of ZnO nanoparticles in the modified GIC [(Chokkattu et al., 2023; Solanki et al., 2023)](https://paperpile.com/c/45pb60/4T9A+xHvz). The diffraction pattern displays sharp peaks, particularly around 36° and 69°, which correspond to the characteristic peaks of ZnO as per the JCPDS card number 008, 82-1042 [(Laghari et al., 2023)](https://paperpile.com/c/45pb60/XovL). This confirms the successful incorporation and crystallinity of ZnO nanoparticles within the GIC matrix. Previous studies such as [(*Website*, n.d.)](https://paperpile.com/c/45pb60/GSqO) suggests that XRD analysis of ZnO nanoparticles for dental use revealed hexagonal crystalline structure with sizes of 47 nm (chemical) and 55 nm (biological), confirming their potential as dental filling agents [(*Anti-Inflammatory Potential Mouthwash Formulated Using Clove Ginger Mediated Zinc Oxide Nanoparticles: Vitro Study*, n.d.; Muthuswamy Pandian et al., 2022)](https://paperpile.com/c/45pb60/T0Ba+fFLM). Also, Comparative studies, such as that by [(Javidi et al., 2014)](https://paperpile.com/c/45pb60/VY8O) says that Zinc oxide nano-particles for dental use exhibited hexagonal wurtzite structures in XRD analysis, indicating their potential as sealers in endodontics for preventing microleakage.The sharp peaks in the XRD pattern observed in this study are consistent with these findings, reinforcing the role of ZnO nanoparticles in enhancing the structural integrity of GICs [(Sreevarun et al., 2023; Wadhwani et al., 2022)](https://paperpile.com/c/45pb60/LygG+Gys4).

The FTIR spectrum shows characteristic peaks at various wavenumbers, including 3300 cm⁻¹ (O-H stretching), 1654 cm⁻¹ (C=O stretching), 1384 cm⁻¹ (C-H bending), 1071 cm⁻¹ (Si-O stretching), and 719 cm⁻¹ (Zn-O stretching). The presence of Zn-O stretching indicates successful incorporation of ZnO nanoparticles into the GIC. Previous research, such as that by [(Torres-Ramos et al., 2022)](https://paperpile.com/c/45pb60/wwVH) has shown that ZnO nanoparticles in dentistry show FTIR peaks indicating functional groups like –OH, C-O, –C-H-, and Zn-O bonds, making them suitable for dental applications as filling agents.The results of this study are in line with these observations, suggesting that the chemical bonding between ZnO nanoparticles and the GIC matrix contributes to the enhanced mechanical properties of the modified cement [(R. K. Jain & Verma, 2022; Marya et al., 2022)](https://paperpile.com/c/45pb60/O0nW+zFd3).

Contact Angle Measurements of unmodified GIC exhibits a contact angle of 68.16°, indicative of hydrophilic surface properties.. In contrast, the contact angle of modified GIC is higher with 85.73° which indicates its more hydrophobic surface. Research conducted by [(Khoroushi & Keshani, 2013)](https://paperpile.com/c/45pb60/XChW) has shown that nanoparticles change the surface energy of dental materials, making it either hydrophilic or hydrophobic. The higher contact angle that was observed in this study is consistent with these findings, showing a surface characteristic transformation for GICs caused by addition of ZnO nanoparticles and which may alter their interaction between the dental tissues (when used as base under restorations) or adhesives [(Ramamurthy et al., 2022)](https://paperpile.com/c/45pb60/5l3Z).

As demonstrated below, surface roughness evaluation shows remarkable variation between the unmodified and ZnO NP-modified GIC [(Chokkattu et al., 2022; Merchant et al., 2022)](https://paperpile.com/c/45pb60/xu5S+fMAq). These values indicate that the unmodified GIC has intense variations in its roughness profile, with surface morphology of relatively high peak-to-valley distances compared to Ra (1.987 µm). A GIC modified with ZnO NPs presents a much smoother surface behavior (Ra, Rq and Rz values of 1.662 µm, 2.091 µm and ranging from ~4 to <20µm respectively) [(Merchant et al., 2022)](https://paperpile.com/c/45pb60/xu5S). After the addition of ZnO NPs, a Fall in the surface roughness could be attributed to an effective filling up or micro-voids present within GIC matrix through finer distribution of added nanoparticles enabling a homogenous and thicker synthesized surface (Saadh et al., 2024). Similar improvements in surface smoothness upon inclusion of nanopatcles The same increase followings paint with nanoparticles addition to GICs has also been reported by the previous studies as well. For instance,[(Garcia-Contreras et al., 2015)](https://paperpile.com/c/45pb60/mE06) demonstrated that the incorporation of TiO2 nanoparticles into GICs resulted in a smooth surface and improved corrosion resistance [(Ganapathy, 2021; Pandiyan et al., 2022)](https://paperpile.com/c/45pb60/RhTg+RoU8). The findings of this study are these results meet, indicating that the added nanoparticles could enhance the surface properties of GICs , which are important for reducing plaque accumulation and improving the resistance to degradation

## Limitations of the Study

Achieving a uniform dispersion of ZnO nanoparticles within the glass ionomer cement (GIC) matrix poses a significant challenge. The risk of agglomeration of nanoparticles can result in an uneven distribution, creating vulnerable areas that may compromise the mechanical properties of the material. It is crucial to determine the optimal concentration of ZnO nanoparticles to avoid adverse effects(Chehelgerdi et al., 2023). Excessive amounts can lead to increased viscosity, making the material challenging to handle and potentially diminishing its overall performance. The long-term stability and durability of ZnO nanoparticle-modified GICs require further investigation, particularly regarding the interaction between the nanoparticles and the cement matrix over extended periods under physiological conditions. This aspect is not yet fully understood and necessitates thorough exploration. Additionally, while ZnO nanoparticles have demonstrated potential in enhancing mechanical properties, thorough evaluation of their biocompatibility is essential. Addressing any potential cytotoxic effects is imperative to ensure the safety of the material for clinical applications.

## Future Scope

Research focuses on functionalizing ZnO nanoparticles to enhance their compatibility with the GIC matrix, enhancing dispersion and interaction. Hybrid nanoparticles, combining ZnO with other nanomaterials, could further enhance the mechanical and biological properties of GICs. Long-term performance studies will assess the durability, stability, and biocompatibility of ZnO NP-modified GICs under physiological conditions. Clinical trials will evaluate the performance in real-world dental applications, assessing effectiveness, safety, and patient outcomes [(Poornima et al., 2021)](https://paperpile.com/c/45pb60/kVrf). Comparative studies with other nanoparticles, such as silver or titanium dioxide, will determine the advantages and potential synergistic effects [(Aparna et al., 2021; Ganapathy, 2021; Verma & Muthuswamy Pandian, 2021)](https://paperpile.com/c/45pb60/mPRX+FzZO+vPjU). Advanced characterization techniques, such as electron microscopy and spectroscopy, will be employed to understand the interactions between ZnO NPs and the GIC matrix at the nanoscale level.

By addressing these limitations and exploring these future research directions, the potential of ZnO NP-modified GICs can be fully realized, leading to improved dental materials with enhanced mechanical properties and clinical performance.

# CONCLUSION

The mechanical properties of conventional glass ionomer cements (GICs) are markedly improved by the addition of zinc oxide nanoparticles (ZnO NPs). These properties include higher toughness and flexural and compressive strength. The enhanced stress distribution and reinforcement of the GIC matrix are credited to ZnO NPs' high surface energy and mechanical characteristics. Nonetheless, there are still issues to be resolved, including finding the ideal concentrations, guaranteeing long-term stability, and verifying biocompatibility, as well as attaining consistent nanoparticle dispersion. To fully realize the promise of ZnO NP-modified GICs, future research should concentrate on nanoparticle functionalization, hybrid nanoparticle use, long-term performance studies, clinical trials, comparison studies with other nanoparticles, and enhanced characterisation techniques.

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