Incorporation of Zinc Oxide Nanoparticles in Ceramic Materials

Incorporación de Nanopartículas de Óxido de Zinc en Materiales Cerámicos

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SECIHTI classification:

Area: Engineering
Field: Technological Sciences
Discipline: Material Technology
Subdiscipline: Ceramic materials

https://doi.org/10.35429/EJT.2025.9.16.2.1.5
History of the article:
Received: June 25, 2025
Accepted: December 19, 2025

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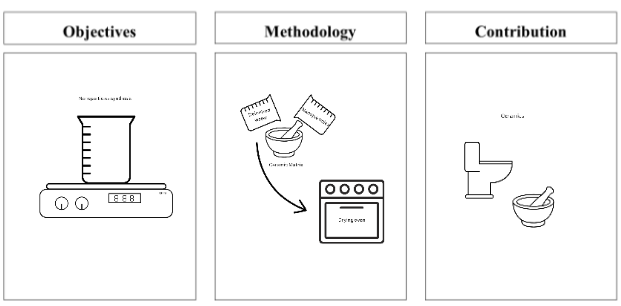
Abstract

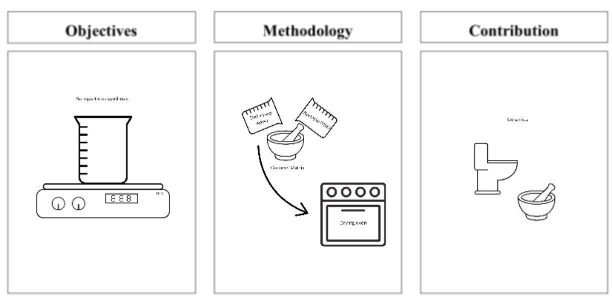
Recently, the incorporation of nanomaterials into industry has increased. The diverse applications of these different nanocomposites have allowed for a wide variety of studies, and with them, their applications have grown. In general, zinc oxide nanocomposites are used for medical applications due to their antimicrobial properties; however, little is known about this material in ceramic applications. This work studies the incorporation of nanostructured materials, such as zinc oxide nanoparticles, into ceramic materials. An XRD and optical microscopy study was performed to ensure the presence of nanoparticles and their effect on the final product.



ZnO, Nanoparticles, ceramics

Resumen

Recientemente la incorporación de nanomateriales en la industria ha ido en aumento, diversas aplicaciones de los diferentes nanocompuestos han permitido una gran variedad estudios y con ello las aplicaciones han crecido. En general los nanocompuestos de óxido de zinc se utilizan para aplicaciones médicas por su capacidad antimicrobiana, sin embargo, poco se habla de este material en aplicaciones cerámicas. En este trabajo se estudia la incorporación de materiales nanoestructurados como lo es las nanopartículas de óxido de zinc en materiales cerámicos. Se realizó un estudio de DRX y microscopia óptica para asegurar la presencia de las nanopartículas y su efecto en el producto final.



ZnO, Nanopartículas, cerámicos

Area: Promotion of frontier research and basic science in all fields of knowledge

Citation: Díaz-Silvestre, Sergio Enrique, Correa-Vazquez, Evanivaldo, Canales-Patiño, Eduardo Luis and Rico-Martinez, Alejandra Hikari. [2025]. Incorporation of Zinc Oxide Nanoparticles in Ceramic Materials. ECORFAN-Journal Taiwan. 9 [16]1-5: e2916105.

Introduction

Zinc oxide nanoparticles (ZnO) have found diverse applications in the ceramics industry due to their unique properties, including enhanced mechanical performance, antibacterial activity, improved thermal conductivity, and use in ceramic coatings, among others. These characteristics make ZnO nanoparticles highly attractive across various scientific fields (Esquivel, 2017; Carreón, 2020). Furthermore, it was reported to use different nanoparticles for the prevention of bacterial biofilms in titanium-based implants (Cajiao, 2025).

In particular, the incorporation of ZnO nanoparticles into ceramic matrices has demonstrated improvements in mechanical strength, thermal stability, and added functionalities such as ultraviolet (UV) radiation protection and antimicrobial capabilities (Surichaqui, 2013). The addition of ZnO can modify the microstructure of ceramics, enabling the development of novel applications in electronic devices, sensors, biomedical materials, and anticorrosive coatings (Bakhsheshi-Rad, 2017; Zhang, 2013; De La Rosa, 2022). In 2025, Quintanilla *et al* worked with epoxy compounds reinforced with silica nanoparticles (Quintanilla Cherrez, 2025). In addition, it was reported the use of silica nanoparticles at different filler contents, as a result of concentration, they improved stability and compressive strength (Conde Alania, 2025).

Moreover, the integration of ZnO nanoparticles into ceramics has shown significant effects in enhancing sintering behavior and reducing processing temperatures, thereby enabling more efficient and cost-effective production of high-performance ceramic materials. Research on the interaction mechanisms between ZnO nanoparticles and the ceramic matrix remains an active area of investigation, as precise control over these interactions is crucial for optimizing the final properties of the resulting materials (De la Garza, 2024).

In recent years, the incorporation of nanostructured materials into ceramics has increased significantly. In particular, zinc oxide nanoparticles have drawn considerable attention due to their antimicrobial properties. However, in other cases, different types of nanoparticles have been introduced into ceramic materials to enhance specific properties.

It should be noted that, despite the growing interest in nanoparticle-modified ceramics, ZnO nanoparticles have not been widely recognized for their potential to improve mechanical strength. Therefore, this study aims to explore the use of ZnO nanoparticles in ceramic materials for a purpose different from those previously reported. While previous studies have demonstrated that the incorporation of nanomaterials can enhance the mechanical resistance of ceramics, the mechanical reinforcement potential of ZnO nanoparticles remains underexplored. This work seeks to address this gap by investigating their role in improving the mechanical properties of ceramic composites.

Methodology

The zinc oxide (ZnO) nanoparticles used in this study were synthesized via the sol-gel method (Martinello, 2012). After synthesis, the ZnO nanoparticles were incorporated into a ceramic matrix by adding all materials simultaneously. Initially, all raw materials in powder form were placed into a ball mill crucible in the quantities specified in Table 1. The following materials were weighed:

Box 1

Table 1
Materials used in the ceramic formulatión

Feldespar
Calcium carbonate
Barium carbonate
Calcium silicate
Silica
Sodium tripolyphosphate
Zirconium silicate
Aluminum silicate
FT-1
ZnO nanoparticles

Created by the authors

The quantities were adjusted to prepare a total of 100 g of sample. The powders were then manually mixed using a spatula to achieve preliminary homogenization. Subsequently, 50 mL of deionized water was added to the mixture, along with one drop of a dispersant (flocculant) to control the suspension of solid particles, aiming to obtain a homogeneous and stable mixture. The slurry was then transferred to a ball mill and milled for 25 minutes to complete the homogenization process.

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https://doi.org/10.35429/EJT.2025.9.16.2.1.5

The resulting liquid mixture was poured into an aluminum dish and placed in a drying oven to remove excess moisture. Once completely dried, the material was ground into a fine powder using a mortar and pestle. The powdered sample was then loaded into a pellet die and compacted into cylindrical pellets using a hydraulic press.

Finally, the green pellets were sintered in a muffle furnace at a predetermined temperature for 16 hours to obtain the final ceramic product. Figure 1 shows photographic images of the ceramic fabrication process.

Box 2

Figure 1
Images of the ceramic fabrication process

The quantities of the materials added were not specified because this is a collaborative project currently under development.

Results

X-ray diffraction (XRD) analysis also confirms the presence of zinc oxide nanoparticles. As shown in Figure 2, the diffraction peak at 37° appearing in the modified sample verifies the successful incorporation of the nanoparticles, consistent with the findings reported by Martinello (Martinello, 2012) and Colonia (Colonia, 2013). According to Martinello and Esquivel, the crystalline structure exhibited by the nanoparticles corresponds to the wurtzite phase.

Box 3

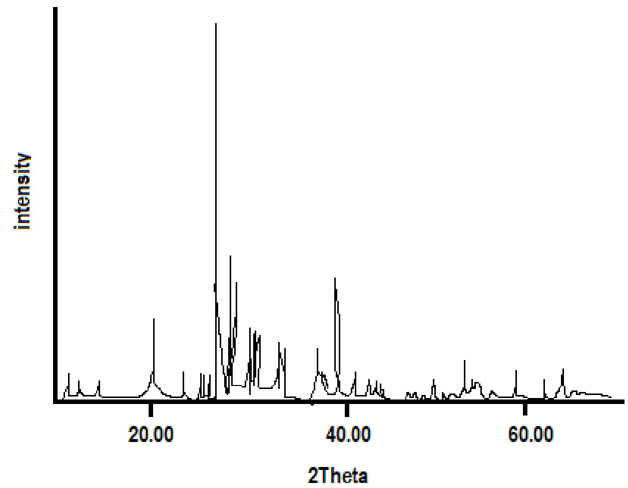

Figure 2
XRD patterns obtained for the unmodified sample and the sample incorporating ZnO nanoparticles
Source: [Origin 2018]

Ceramic product fabrication

The results after the sintering process show good densification of the material and adequate mechanical strength for ceramic coatings. The properties of zinc oxide nanoparticles are expected to enable the dispersion and reflection of ultraviolet (UV) radiation.

The incorporation of nanomaterials into the ceramic matrix was successful. As observed in the micrographs, the modified ceramic exhibits a surface with finer cracks, indicating a reduced grain size. This refinement suggests an improvement in mechanical strength. Figure 3 presents the fabricated ceramic samples, comparing the unmodified material (without nanoparticle addition) with the modified ceramic containing ZnO nanoparticles.

Box 4

Figure 3
Ceramic materials fabricated without modification (left side) and modified (right side) with the incorporation of ZnO nanoparticles using optical microscope
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ISSN: 2524-2121
RENIECYT-SECIHTI: 1702902

(De la Garza, 2024) reports in their study that porosity has a direct impact on the properties of ceramic tiles, concluding that the addition of ceramic oxide nanoparticles significantly reduces porosity in ceramic tiles. In another study, the incorporation of nanomaterials was shown to enhance the physical, mechanical, thermal and thermo-mechanical properties of refractory materials, depending on the concentration range and type of nanomaterial used (Carreón, 2020).

The study with other nanoparticles such as silica oxide as reinforcement demonstrated that they improve mechanical properties, therefore it is considered that the use of zinc oxide nanoparticles can improve mechanical properties in addition to contributing as a bacteria inhibitor on surfaces. (Quintanilla Cherrez, 2025), (Conde Alania, 2025).

The fabricated ceramic material was analyzed via micrographs. As shown in Figure 4, three optical microscope images reveal surface differences between the samples. In the unmodified material, small edge features are visible, which may indicate microcracks. In contrast, these features are not observed in the modified sample.

Although the modified sample appears to exhibit scratches that could be mistaken for fractures, these are artifacts resulting from surface scraping performed to reduce light reflection, as the modified material exhibited higher whiteness.

Box 5

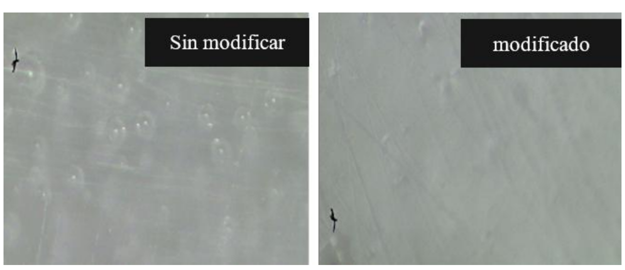

Figure 4
Micrographs of the unmodified ceramic material and the ceramic modified with ZnO nanoparticles. Image taken from the Quasar Qm 33 Science microscope

Conclusions

The incorporation of ZnO nanoparticles was successfully achieved and carried out without complications during the mixing process.

The addition of ZnO nanoparticles has the potential to increase the hardness and abrasion resistance of the ceramic coating, enhancing its durability and resistance to wear — findings that are consistent with previous literature regarding the influence of nanoparticle morphology. As observed in this study, the surface appearance of the modified ceramic is promising for application in the ceramic industry. However, further mechanical strength tests are required to confirm the improved performance of the modified material, as microstructural analysis revealed a reduction in crack formation, suggesting enhanced mechanical integrity.

Declarations

Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this article.

Author contribution

Evanivaldo Correa Vazquez: Contributed to investigation, material synthesis, and writing – original draft.

Sergio Enrique Díaz Silvestre: Contributed to conceptualization, project administration, writing – review & editing.

Eduardo Canales Patiño: Contributed to methodology, data analysis, and interpretation of results.

Alejandra Hikari Rico Marinez: Contributed to conceptualization and validation of results.

Availability of data and materials

Further information regarding the data is available upon request. Please contact the corresponding author for inquiries.

Funding

This work was supported by the Universidad Tecnológica de Saltillo.

Acknowledgements

The authors thank Ing. Fernando Molina for his support in the preparation of the ceramic materials.

Abbreviations

Zno	Zinc oxide
XRD	X-ray Diffraction

References

Antecedents

H. R. Bakhsheshi-Rad E. Hamzah A.F. Ismail M. Aziz M. Kasiri-Asgarani E. Akbari S. Jabbarzare A. Najafinezhad Z. Hadisi. (2017). Synthesis of a novel nanostructured zinc oxide/baghdadite coating on Mg alloy for biomedical application: In-vitro degradation behavior and antibacterial activities. Ceramics International 43(17), 14842–14850.

Roberto Colonia, Vanessa C. Martínez, José L. Solís, Mónica M. Gómez. (2013). Síntesis de nanopartículas de ZnO2 empleando ultrasonido: caracterización estructural y morfológica para aplicaciones bactericidas. Revista de la Sociedad Química del Perú, 79(2), 126-135.

Y. Zhang T.R. Nayak H. Hong W. Cai. (2013). Biomedical Applications of Zinc oxide Nanomaterials. Current Molecular Medicine, 13(10), 1633-16–45.

Cajiao Checchin, Valentina Chiara. (2025). Desarrollo de nanoestructuras de óxido de titanio y nanopartículas/nanopelículas para la prevención de la formación de biofilms bacterianos sobre materiales implantables de base titanio. Tesis de doctorado. Universidad Nacional de La Plata

Basics

Bruna Martinello Savi, Larissa Rodrigues, Adriano Michael Bernardin. (2012). Síntesis de Nanopartículas de ZnO por el Proceso SOL-GEL. En QUALICER (Ed.), Qualicer 12.

Luis Alejandro Esquivel Rodríguez, María Blanca Nieves Cancino González. (2017). Estudio de las propiedades antimicrobianas de nanopartículas de ZnO y ZnO/Ag sintetizadas por el método de reacción en microemulsión" [Tesis de maestría, Centro de Investigación en Materiales Avanzados S. C.].

Supports

De La Garza, D. A. A. (2024). Efecto de la Adición de Nanopartículas Cerámicas en la Microestructura y Propiedades de Baldosas Cerámicas [Tesis de Doctorado, Universidad Autónoma de Nuevo León].

Surichaqui, R. C. C. (2013). Síntesis y Caracterización de nanopartículas de ZnO2 y su actividad antimicrobiana [Tesis de licenciatura, Universidad Nacional de Ingeniería].

Differences

De La Rosa-Reta Héctor Zermeño-González Magdalena Galindo-Guzmán, A. P. G.-G. M. F.-H. C. V. (2022). Síntesis química de nanopartículas de óxido de zinc y su evaluación en plántulas de Lactuca sativa. Revista Mexicana de Ciencias Agrícolas, 13(28), 299-308.

Discussions

Marco Vinicio Carrión V. & Fernanda Pilaquinga F. (2 de junio 2020). Nanotecnología Aplicada en Materiales Refractarios: Una Revisión. InfoANALÍTICA, 8(2), 21–44.

Quintanilla Cherrez, A. D. (2025). Caracterización mecánica de materiales compuestos de matriz epóxica reforzados con partículas a base de dióxido de silicio: componente A: caracterización mecánica de materiales compuestos de matriz epóxica reforzados con nanopartículas de sílice. 85 páginas. Quito :EPN.

Conde Alania, E. S., & Ñañez Saldaña, D. I. (2025). Efecto de la aplicación de nanopartículas de óxido de silicio como filler en las propiedades físicas y mecánicas de mezclas asfálticas frías Huancayo 2024. [Tesis de licenciatura, Universidad Continental]. Repositorio Institucional Continental.