

Investigation into the Ballistic Performances of Sisal Fibre Reinforced Epoxy Resin-Zinc Oxide Nanocomposites

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ABSTRACT

Epoxy resin-based nanocomposites have gained significant attention in ballistic applications due to their lightweight, high strength, and impact resistance. This study investigates the ballistic performance of epoxy resin-zinc oxide (ZnO) nanocomposites reinforced with sisal fibre. The nanocomposites were prepared by dispersing varying weight fractions of ZnO nanoparticles into the epoxy matrix supported sisal fibre, followed by curing under controlled conditions. Energy dispersive spectroscopy (EDS) was used to analyze the nanoparticles dispersion. Energy absorption capability was evaluated to understand the effect of ZnO reinforcement on the material. Ballistic tests were conducted using high-velocity impact simulations to assess the penetration resistance and failure mechanisms. The results demonstrated that the addition of ZnO nanoparticles enhances the ballistic performance of the epoxy resin reinforced with sisal fibre by geometrically increased its absorption energy from 46.64J to 238.88, 195.82, and 165.67J for the nanocomposites (E-ZnO1, E-ZnO3, and E-ZnO5) respectively. The findings suggest that Epoxy/ZnO nanocomposites supported with sisal fibre can be a promising material for lightweight armour applications, offering a balance between strength and flexibility.

ARTICLE INFO

Article History

Received: October, 2024

Received in revised form: December, 2024

Accepted: February, 2025

Published online: March, 2025

KEYWORDS

Epoxy resin, Zinc oxide nanoparticles, Nanocomposites, Ballistic performance, and Energy absorption

INTRODUCTION

Epoxy resin/zinc oxide (ZnO) nanocomposites have garnered significant attention due to their potential applications in fields requiring enhanced mechanical and ballistic properties (Mohammed *et al.*, 2023). The integration of ZnO nanoparticles into an epoxy matrix aims to leverage the unique properties of both components, resulting in materials with superior performance characteristics (Somogh *et al.*, 2024).

Epoxy resins are thermosetting polymers known for their excellent mechanical strength, chemical resistance, and adhesive properties. They are widely used in coatings, adhesives, and composite materials (El-Sabban and Deyab, 2023). Zinc oxide, a semiconductor material with a wide band gap, exhibits notable mechanical strength, UV absorption, and

antimicrobial properties. When reduced to the nanoscale, ZnO particles offer a high surface area-to-volume ratio, enhancing their interaction with polymer matrices and leading to improved composite properties (Zhou *et al.*, 2023).

The fabrication of epoxy resin/ZnO nanocomposites typically involves the dispersion of ZnO nanoparticles into the epoxy resin, followed by curing. Achieving a uniform dispersion of nanoparticles is crucial, as agglomeration can detrimentally affect the composite's properties (Folorunso *et al.*, 2024). Thus, techniques like ultrasonic agitation and the use of surfactants are employed to ensure homogeneous distribution of ZnO nanoparticles within the epoxy matrix (Seo, Kim and Kwon, 2023).

The incorporation of nanoparticles into epoxy resins has been investigated to enhance the ballistic performance of the resulting

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nanocomposites (Rashid *et al.*, 2024; Megahed *et al.*, 2024). Studies have shown that the addition of nanoparticles can improve impact resistance and energy absorption capabilities (Taghipoor and Ghiaskar, 2024). For instance, research on Kevlar fiber-reinforced epoxy composites filled with nanoparticles demonstrated that the inclusion of nanocarbon particles at varying concentrations influenced the ballistic performance of the composites (Rashid *et al.*, 2024). However, the specific impact of nanoparticles on ballistic performance requires continuous investigation.

Beyond mechanical enhancements, metal oxide nanoparticles also affect the dielectric properties of epoxy composites. Dielectric relaxation studies have revealed that the presence of metal nanoparticles influences the molecular mobility and interfacial polarization within the composite (Blejja *et al.*, 2024). These changes can impact the material's performance in applications where dielectric properties are critical. Therefore, epoxy resin/metal nanocomposites represent a promising class of materials with enhanced properties suitable for various advanced applications. While significant progress has been made in understanding their characteristics, continued research is essential to fully elucidate the mechanisms by which ZnO nanoparticles influence the ballistic and mechanical performance of epoxy-based composites.

MATERIALS AND METHODS

Materials

Neem leaves were collected within Nigerian Defence Academy Afaka, Kaduna State while the Sisal fibre at a farm in Samaru Zaria. Commercial epoxy resin, Cobalt Naphthenate, 4% Sodium Hydroxide and Zinc Acetate Dihydrate were used as purchased from Sigma Aldrich.

METHODS

Samples Pre-treatment

Neem and Sisal leaves were washed with tap water to remove dust and other impurities. Neem leaves were dried and preserved at room temperature until use.

Extraction of Sisal Fibres

The sisal leaves undergone retting for 24 hours to extract sisal fibres using the decortication method. The extracted sisal fibres were treated using 40g of NaOH in 1000 cm³ distilled water at 60°C for 15 minutes. Thereafter, the treated sisal fibres were soaked in the NaOH solution for 1hour, removed, washed with distilled water until a neutral pH, and dried at 60 °C for 4 hours.

Biosynthesis of Zinc Oxide Nanoparticles

The zinc oxide nanoparticles were synthesized using aqueous extract of Neem leaves. In this context, 20g of the pulverized dried Neem leaves in 100 cm³ distilled water were heated at 60°C for 20 minutes to obtain a pale yellow solution. The solution was allowed to cool at room temperature and filtered using Whatman No.1 filter paper. 2.0g of zinc acetate dihydrate was dissolved in 100 cm³ distilled water, followed by addition of 20 cm³ of the neem extract with constant stirring until the mixture becomes clear, the clear solution was heated slowly at 60°C, until the solution became deep yellow-coloured paste. The paste was heated at 400°C for 2 hours in a muffle furnace to obtain the zinc oxide nanoparticles.

Dispersion of Zinc Oxide Nanoparticles in Epoxy Resin and Preparation of Nanocomposite Laminates

The prepared Zinc Oxide nanoparticles were dispersed in the epoxy matrix in different compositions (1 – 5 wt. %) using a high-speed disperser at 1000 rpm for 30 minutes. The nanocomposite laminates were prepared using Handlay-up processing technique. In this technique, MEKP catalyst, 1wt. % of epoxy resin and ZnO-filled epoxy resin were mixed and stirred for 2 minutes followed by the addition of Cobalt Naphthenate accelerator to initiate the curing of the epoxy resin before reinforcement. The mixture was again properly stirred to mix the catalyst and initiator in the matrix. The resulting mixture was uniformly poured on the four layers of cross-woven sisal fibre mat with dimensions of 178mm x 178mm x20mm placed separately on aluminium

foil at the work table. Finally, these layers were stacked on one another and wrapped in aluminium foil to obtain the nanocomposites laminates. Subsequently, hot compression moulding technique was employed to post-cure the nanocomposite and its laminates. The 178mm x 178mm x 20mm stainless steel mould of High-

Temperature Melt Press made was used to post-cure the nanocomposite and laminates under a pressure of 2.844 psi for 1h at 80°C and 60°C to obtained uniform thickness respectively. The samples were removed from the mould as the final product. The formulation of various nanocomposites is given Table 2:

Table 1: Nanocomposite Mixture of Laminate

S/N	Matrix Content (wt. %)	Zinc Oxide (wt. %)	Composite Content (wt. %)	Sample
1	50	0	50	E (Epoxy resin)
2	49	1	50	E-ZnO1
3	47	3	50	E-ZnO3
4	45	5	50	E-ZnO5

Characterization of the Prepared Zinc Oxide Nanoparticles and its Nanocomposites

The prepared zinc oxide nanoparticles and its nanocomposites with epoxy resin were characterized by determining their absorption bands, functional groups, elemental composition, and mineralogical phases by UV-Visible spectrophotometry, FTIRS, EDX, and XRD respectively.

Ballistic Test

The ballistic test was performed on the nanocomposite to evaluate its kinetic energy absorption capacity. The nanocomposite plate as target was cut to dimensions 12 x 7 x 1.2 cm for the test and place such that an Air Chrony ballistic chronograph with a precision of 0.15 m/s and a ProChrono ballistic chronograph with a precision of 0.31 m/s were used to measure the impact and residual velocities respectively. The energy

absorbed by the target was calculated using equation 1:

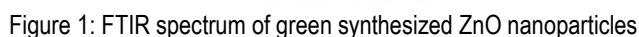
$$E_{\text{abs}} = \frac{m_p(v_i^2 - v_r^2)}{2} - E_0 \quad 1$$

Where m_p is the mass of the projectile, v_i is the impact speed, v_r residual speed and E_0 is the energy dissipated by the projectile only by air-flying without a target.

RESULTS AND DISCUSSION

Fourier Transform Infrared (FTIR) Spectroscopy of Zinc Oxide Nanoparticles

The FTIR measurement was carried out using KBr pellet method at room temperature through the wave range 4000 - 400 cm^{-1} as shown in Figure 1. This was done to identify the possible biomolecules responsible for capping and stabilization of the biosynthesized zinc oxide nanoparticles. It is also to indicate the reduction of metal (zinc) ions by the used aqueous extract.



X-ray diffraction of Zinc Oxide Nanoparticles

From the Figure 2, the diffraction pattern of the biosynthesized zinc oxide nanoparticles show seven typical peaks at 2θ values of 31.40, 34.41, 36.20, 56.57, 62.87 and 69.019° and 77.02° corresponding to (100), (002), (101), (102), (110), (103) and (201) plane of zinc oxide nanoparticles and compared with the standard powder diffraction card of Joint Committee on Powder Diffraction Standards (JPCDS) card number 36-1451. The XRD study confirmed the formation of a crystalline hexagonal wurtzite structure of the ZnO nanoparticles (Faisal *et al.*, 2021).



Additionally, a typical high intense peak generally index as (101) observed in the diffractogram shows that the zinc oxide nanoparticles formed by the Neem leaf extract are crystalline in nature while a broaden peak at 2θ of 36.200 signifies smaller particle size (Salem et al., 2022).

Electron Dispersive Spectra (EDS) of epoxy resin, zinc oxide nanoparticles and epoxy resin–zinc oxide nanocomposites (E-ZnO1, E-ZnO3, and E-ZnO5)

Electron dispersive spectroscopy (EDS) is a technique used to examine the presence of elements through the amplitudes of the

wavelength of the x-rays emitted after their electrons have been hit by some electron beam (Ali, Zhang, and Santos, 2023). For X-ray to be emitted, the atoms must contain minimum of K-shell and L-shell where the electron is allowed to dislodge from shell to shell. Therefore, hydrogen, being the only element in the periodic table with only K - shell is not detectable with EDS (Pushie et al., 2014). Figures 3 a, b, c, d and e show the EDS of epoxy resin, zinc oxide nanoparticles and epoxy resin–zinc oxide nanocomposites (E-ZnO1, E-ZnO3, and E-ZnO5) respectively prepared in this study.

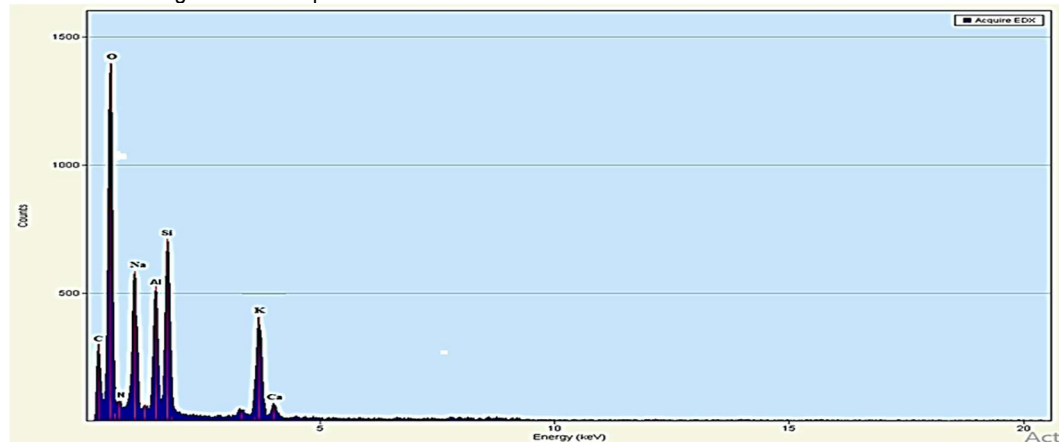


Figure 3a: EDS Spectrum for Epoxy Resin (E)

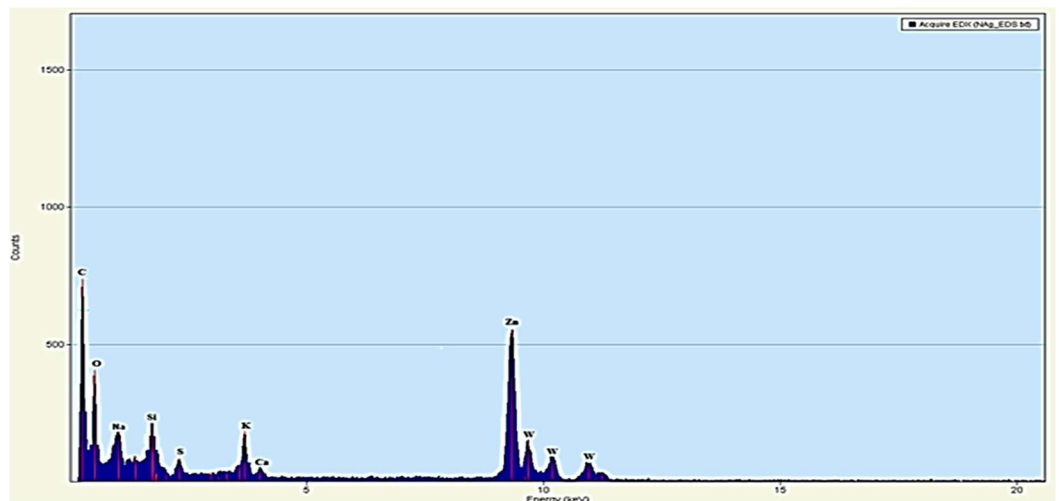


Figure 3b: EDS Spectrum of Zinc Oxide Nanoparticles

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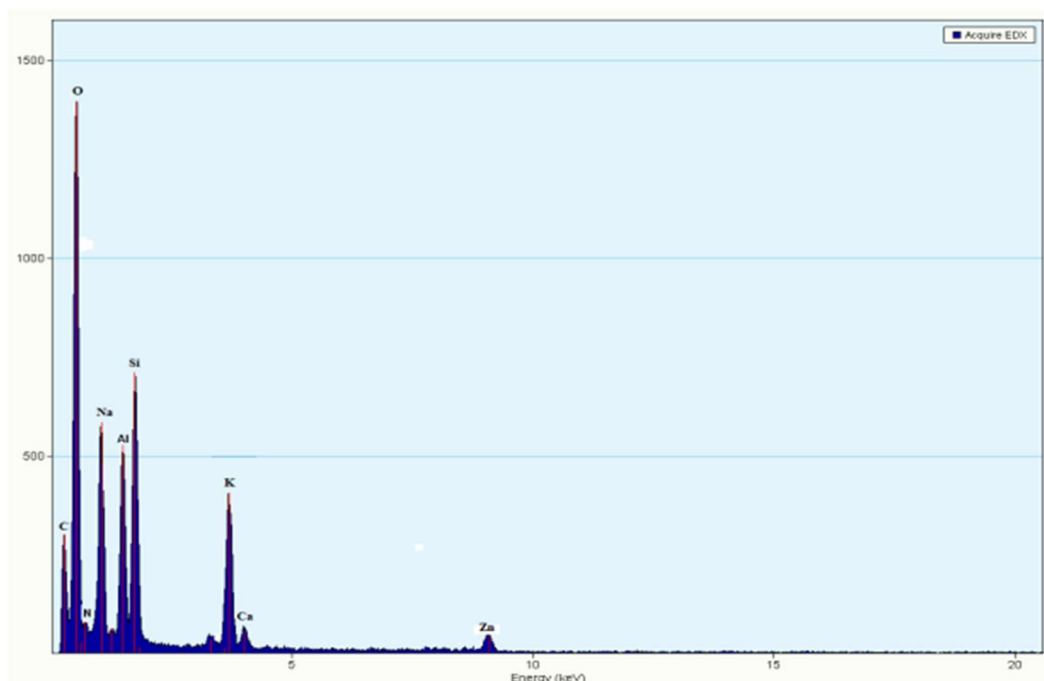


Figure 3c: EDS Spectrum of Epoxy Resin- Zinc Oxide Nanocomposite (E-ZnO1)

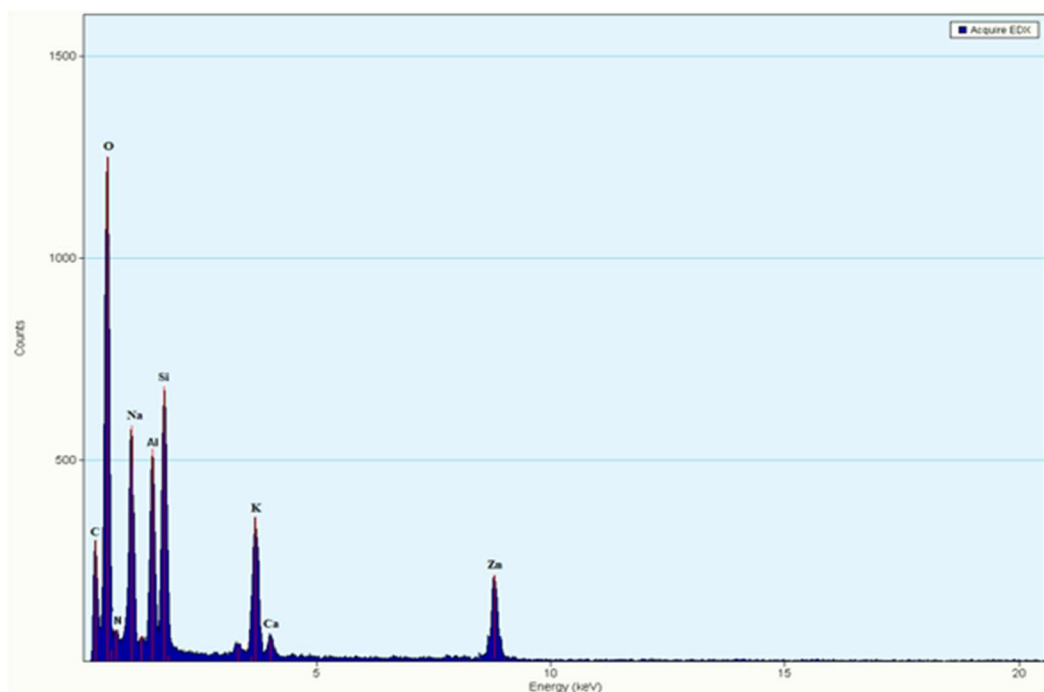


Figure 3d: EDS Spectrum of Epoxy Resin- Zinc Oxide Nanocomposite (E-ZnO3)

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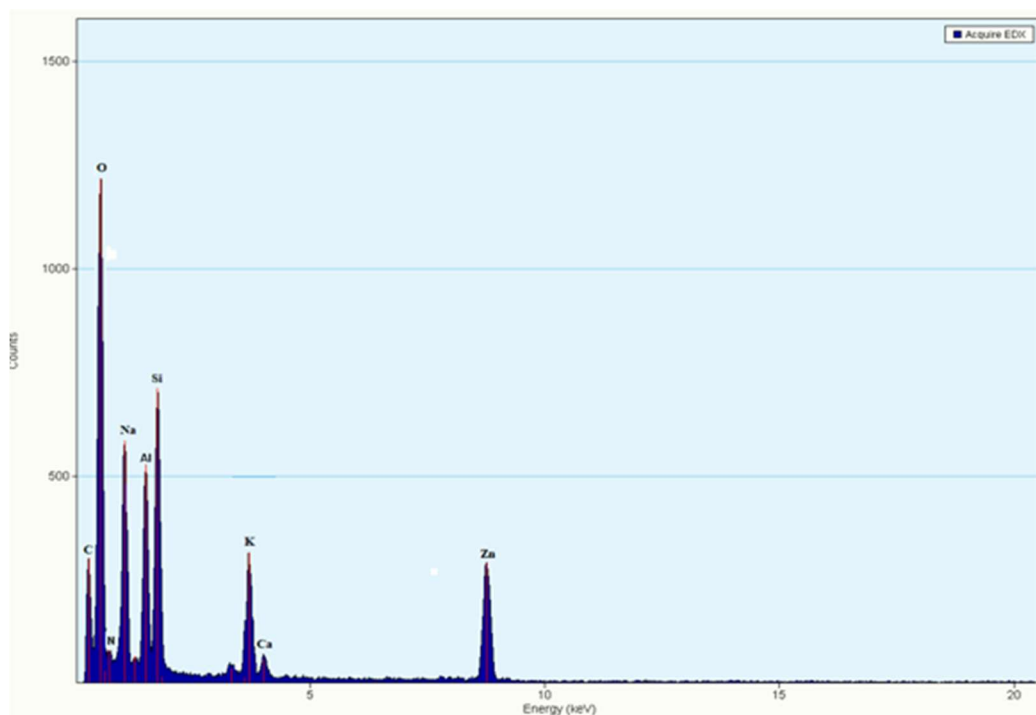


Figure 3e: EDS Spectrum of Epoxy Resin- Zinc Oxide Nanocomposite (E-ZnO5)

Figure 3a is the EDS for the prepared epoxy resin and the spectrum shows the key elements (carbon, nitrogen and oxygen) in the surface chemical structure of the epoxy resin. Figure 3b is the EDS spectrum of the prepared zinc oxide nanoparticles and the spectrum shows presence of the strong signal characteristic of elemental zinc around 8 - 9keV which is typical of metallic zinc as a result of surface plasmon resonance, thus verify the formation of zinc oxide nanoparticles (Orshiso *et al.*, 2023). The EDS spectra (Figure 3c, d and e) of epoxy resin-zinc oxide nanocomposites show the peaks for the elements (C, N, O and Ag) that make up both epoxy resin and zinc oxide nanoparticles.

The presence of signals of Al, Ca, K, and Na in the EDS of epoxy resin and its nanocomposites may be attributed to strong bond formed by these elements as a macronutrient commonly found in nature (Shelly *et al.*, 2024). The EDS result of zinc oxide nanoparticles (Figure 3c) shows signals similar to that of Ca, K, Na, and S which might have originated from the

biomolecules of the leaf extract that are bound to the surface of zinc oxide nanoparticles (Murali *et al.*, 2021). The signal for sulphur was not observed in the nanocomposites and this shows that it has been removed through the downstream treatment of the nanocomposite. Also observed in the EDS are signals similar to silicon in all the prepared samples and tungsten in the prepared zinc oxide nanoparticles which may be attributed to interferences of debris of silicon-lithium detector and hot tungsten filament as components of the machine used for a long time (Chavali and Nikolova, 2019). The presence of zinc on the epoxy resin surface as shown by the EDS confirmed the successful preparation of the epoxy resin-zinc oxide nanocomposites.

Ballistic Performance of the Prepared Epoxy Resin/Nanocomposites and the Effect of Varying Zinc Oxide Nanoparticles Contents on the Ballistic Performance of the Composite

In this study, the ballistic performance of the prepared epoxy resin and its nanocomposites

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is explained using energy absorptions and limit velocities obtained from impact and residual velocities.

The impact velocity is the velocity of a projectile when it undergoes collision with the samples (epoxy resin and its nanocomposites) while a residual velocity is a velocity of the projectile after the impact against the epoxy and nanocomposite targets. The limit velocity also known as ballistic limit is the velocity required for a particular projectile to reliably penetrate a particular prepared sample (Husain *et al.*, 2024).

In other words, a given projectile will generally not pierce a given sample when the projectile velocity is lower than the ballistic limit. Also, ballistic limit velocity is the velocity required for a projectile to penetrate a target with 50 percents of time and is widely used as a measure of armour (Stewart and Netherton, 2020).

The results of ballistic test in the form of impact velocities (V_i), residual velocities (V_r), energy absorptions (E_{abs}), and limit velocities (V_L) values for each sample are presented in Figures 4 and 5.

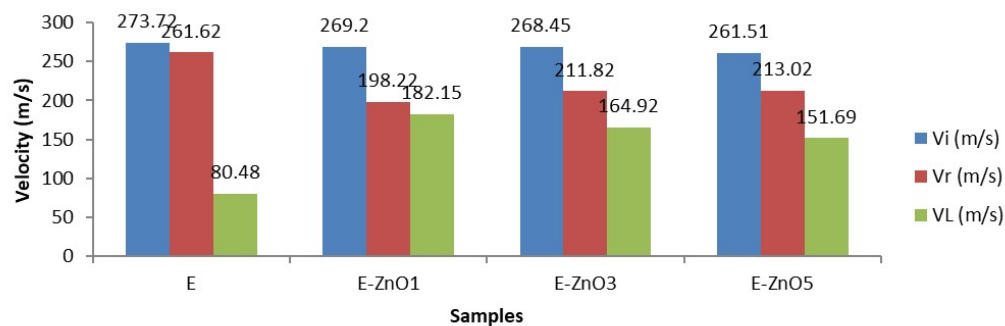


Figure 4: Impact, Residual and Limiting Velocities of Epoxy resin and its Nanocomposites

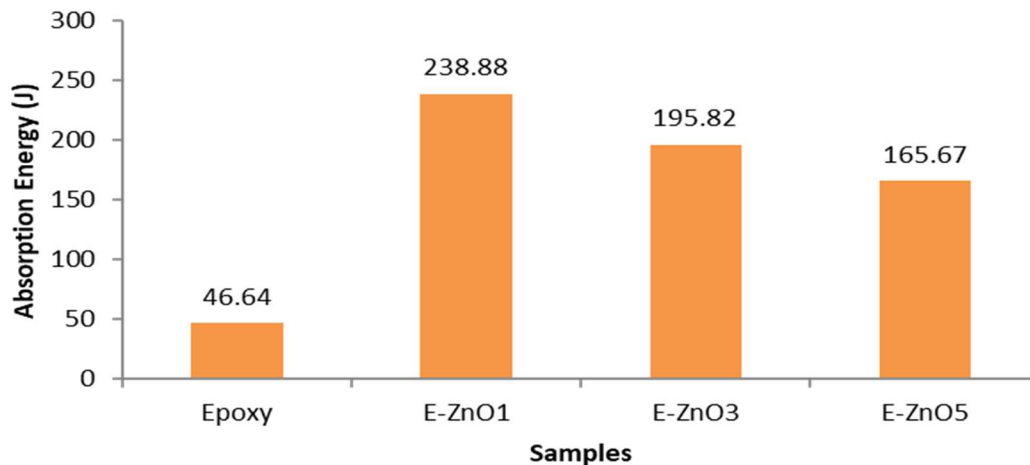
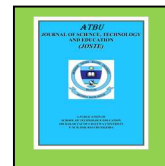


Figure 5: Absorption Energies (J) of Epoxy and its Nanocomposites

Regarding ballistic resistance against projectile among the samples, the E-ZnO1 nanocomposites showed the highest absorption energy (238.88J). This indicates that the nanocomposite has a better ability for absorption

with little or no rupture, allowing it to survive a greater number of shots. Also, among the samples, E-ZnO1 exhibits the highest limit velocity (V_L) of 182.15 m/s. This implies that the projectile had its velocity speed significantly resisted



meaning larger resistance to the projectile impact, signifying better ballistic resistance due to the presence of zinc oxide nanoparticles and silas fibres (Purwanto *et al.*, 2022).

Meanwhile, the absorption energies and limit velocities of nanocomposites were found to be decreasing as the zinc oxide nanoparticles content in the nanocomposite increases. The results were similar to results reported by Chaves *et al* (2024) in their study of mechanical and ballistic properties of epoxy composites reinforced with *Babassu fibres* where 10, 20, and 30vol. % of

Babassu fibres in the epoxy matrix were used. One possible explanation for this could be the arrangement of the fibres within the matrix (Chaves *et al.*, 2024). Therefore, for engineering applications, these nanocomposites still require further studies, which could improve their properties through chemical treatments. However, for ballistic applications, the blend of silas fibre with epoxy resin in the presence of zinc oxide nanoparticles shows great potential.

Table 2: ANOVA of Ballistic Properties

Source of Variation	Sums of squares	Degrees of freedom	Mean square	F-cal	P-value	F-crit
Between Groups	27919.67	3	9306.557	58.3488	1.99E-07	3.49029
Within Groups	1913.981	12	159.4984	9		5
Total	29833.65	15				

The values of absorption energies obtained from ballistic test were subjected to the ANOVA test. This analysis allowed determining the reliability of the influences of zinc nanoparticles, which vary from 0 to 5wt%. The results of this analysis are presented in Table 2. Table 2 shows that F-calculated is greater than F-critical because the value of F-calculated is 58.35 and F-critical is 3.49. Thus, it can be concluded that varying proportion of zinc oxide nanoparticles in the nanocomposites significantly influence absorption energy (E_{abs}).

CONCLUSION

The study on the ballistic performance of sisal fibre-reinforced epoxy resin-zinc oxide (ZnO) nanocomposites has provided valuable insights into their impact resistance and energy absorption characteristics. The results indicate that the incorporation of ZnO nanoparticles enhances the ballistic properties of the composite by improving its energy absorption capabilities. Compared to pure epoxy or conventional fibre-reinforced composites, the developed nanocomposite shows superior ballistic

resistance, making it a promising candidate for protective applications.

This study demonstrates that sisal fibre-reinforced epoxy resin-ZnO nanocomposites offer a sustainable and efficient alternative for ballistic protection. Further research on processing techniques, fibre-matrix interaction, and real-world testing could help optimize these materials for defense, automotive, and aerospace applications.

REFERENCES

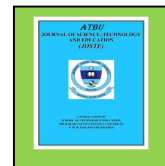
- Ali, A., Zhang, N., & Santos, R. M. (2023). Mineral Characterization Using Scanning Electron Microscopy (SEM): A Review of the Fundamentals, Advancements, and Research Directions. *Applied Sciences*, 13(23), 12600. <https://doi.org/10.3390/app132312600>.
- Blejja, M., Platnieks, O., Starkova, O., Macutkevič, J., Tsyhanok, D., Orlova, L., & Gaidukovs, S. (2024). Evaluation of thermal conductivity models and dielectric properties in metal oxide-filled poly (butylene succinate-co-adipate)

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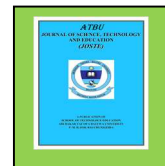
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- composites. *Scientific Reports*, 14(1).
<https://doi.org/10.1038/s41598-024-64426-5>.
- Chavali, M. S., & Nikolova, M. P. (2019). Metal oxide nanoparticles and their applications in nanotechnology. *SN Applied Sciences*, 1(6).
<https://doi.org/10.1007/s42452-019-0592-3>.
- Chaves, Y. S., Monteiro, S. N., Nascimento, L. F. C., & Rio, T. G. (2024). Mechanical and Ballistic Properties of Epoxy Composites Reinforced with Babassu Fibers (*Attalea speciosa*). *Polymers*, 16(7), 913.
<https://doi.org/10.3390/polym16070913>
- El-Sabban, H. A., & Deyab, M. A. (2023). Novel highly efficient ternary ZnO wrapped PPy-NTs/g-C₃N₄ nanocomposite as an epoxy coating for corrosion protection. *Scientific reports*, 13(1), 21410. <https://doi.org/10.1038/s41598-023-48557-9>.
- Folorunso, O., Hamam, Y., Sadiku, R., & Kupolati, W. (2024). Effects of defects on the properties of polymer nanocomposites: A brief review. *Journal of Inorganic and Organometallic Polymers and Materials*.
<https://doi.org/10.1007/s10904-024-03179-0>.
- Husain, A., Danish, M., Khan, S. H., & Mourad, A. I. (2024). Predicting projectile residual velocities using an advanced artificial neural network model. *Heliyon*, 10(11), e32149.
<https://doi.org/10.1016/j.heliyon.2024.e32149>.
- Megahed, M., Sakr, A. S., Badawy, A. a. M., & Seleem, M. H. (2024). Assessment of the performance of aluminum, copper, and graphene nanometer fillers filled woven glass fiber/epoxy composites. *Journal of Polymer Research*, 31(2).
<https://doi.org/10.1007/s10965-024-03870-3>.
- Mohammed, M., Oleiwi, J. K., Jawad, A. J. M., Mohammed, A. M., Osman, A. F., Rahman, R., Adam, T., Betar, B. O., Gopinath, S. C. B., & Dahham, O. S. (2023). Effect of zinc oxide surface treatment concentration and nanofiller loading on the flexural properties of unsaturated polyester/kenaf nanocomposites. *Heliyon*, 9(9), e20051.
<https://doi.org/10.1016/j.heliyon.2023.e20051>.
- Murali, M., Kalegowda, N., Gowtham, H. G., Ansari, M. A., Alomary, M. N., Alghamdi, S., Shilpa, N., Singh, S. B., Thriveni, M. C., Aiyaz, M., Angaswamy, N., Lakshmidevi, N., Adil, S. F., Hatshan, M. R., & Amruthesh, K. N. (2021). Plant-Mediated Zinc Oxide Nanoparticles: Advances in the New Millennium towards Understanding Their Therapeutic Role in Biomedical Applications. *Pharmaceutics*, 13(10), 1662.
<https://doi.org/10.3390/pharmaceutics13101662>.
- Orshiso, T. A., Zereffa, E. A., Murthy, H. C. A., Demissie, T. B., Pardeshi, O., Avhad, L. S., & Ghotekar, S. (2023). Biosynthesis of *Artemisia abyssinica* Leaf Extract-Mediated Bimetallic ZnO–CuO Nanoparticles: Antioxidant, Anticancer, and Molecular Docking Studies. *ACS Omega*, 8(44), 41039–41053.
<https://doi.org/10.1021/acsomega.3c01814>.
- Purwanto, H., Tauviqirrahman, M., Sugiarto, S., & Dzulfikar, M. (2022). Analysis projectile performance in ballistic tests using compressed air gun. *EUREKA Physics and Engineering*, 6, 120–127.
<https://doi.org/10.21303/2461-4262.2022.002418>.
- Pushie, M. J., Pickering, I. J., Korbas, M., Hackett, M. J., & George, G. N. (2014). Elemental and chemically specific X-ray fluorescence imaging of biological



- systems. *Chemical reviews*, 114(17), 8499–8541.
<https://doi.org/10.1021/cr4007297>.
- Rashid, A. B., Haque, M., Islam, S. M. M., & Uddin Labib, K. M. R. (2024). Nanotechnology-enhanced fiber-reinforced polymer composites: Recent advancements on processing techniques and applications. *Heliyon*, 10(2), e24692.
<https://doi.org/10.1016/j.heliyon.2024.e24692>.
- Seo, J. H., Kim, K. M., & Kwon, J. S. (2023). Antibacterial and Physicochemical Properties of Orthodontic Resin Cement Containing ZnO-Loaded Halloysite Nanotubes. *Polymers*, 15(9), 2045.
<https://doi.org/10.3390/polym15092045>
- Shelly, D., Singhal, V., Singh, S., Nanda, T., Mehta, R., Lee, S. -Y., & Park, S. -J. (2024). Exploring the Impact of Nanoclay on Epoxy Nanocomposites: A Comprehensive Review. *Journal of Composites Science*, 8(12), 506.
<https://doi.org/10.3390/jcs8120506>.
- Sohail, M. F., Rehman, M., Hussain, S. Z., Huma, Z., Shahnaz, G., Qureshi, O. S., Khalid, Q., Mirza, S., Hussain, I., & Webster, T. J. (2020). Green synthesis of zinc oxide nanoparticles by Neem extract as multi-facet therapeutic agents. *Journal of Drug Delivery Science and Technology*, 59, 101911.
<https://doi.org/10.1016/j.jddst.2020.101911>.
- Şomoghi, R., Mihai, S., Teodorescu, G. -M., Vuluga, Z., Gabor, A. R., Nicolae, C. -A., Trică, B., Vătău, D. M. S., Oancea, F., & Stănculescu, C. M. (2024). Influence of HNT-ZnO Nanofillers on the Performance of Epoxy Resin Composites for Marine Applications. *Coatings*, 14(5), 532.
<https://doi.org/10.3390/coatings14050532>.
- Stewart, M. G., & Netherton, M. D. (2020). Statistical variability and fragility assessment of ballistic perforation of steel plates for 7.62 mm AP ammunition. *Defence Technology*, 16(3), 503 - 513,
<https://doi.org/10.1016/j.dt.2019.10.013>
- Taghipoor, H., & Ghiaskar, A. (2024). Optimized enhanced energy absorption in polymer nanocomposites reinforced with nano-clay, nano-silica, and diethylenetriamine. *Scientific Reports*, 14(1). <https://doi.org/10.1038/s41598-024-77960-z>.
- Zhou, X.-Q., Hayat, Z., Zhang, D.-D., Li, M.-Y., Hu, S., Wu, Q., Cao, Y.-F., & Yuan, Y. (2023). Zinc Oxide Nanoparticles: Synthesis, Characterization, Modification, and Applications in Food and Agriculture. *Processes*, 11(4), 1193.
<https://doi.org/10.3390/pr11041193>.