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EVALUATION OF THE PHYSICO-MECHANICAL/CHEMICAL PROPERTIES OF CORNCOB-GROUNDNUT SHELL HYBRID COMPOSITE

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Abstract. This study investigates the development and characterization of sustainable hybrid bio composites reinforced with groundnut shell (GNS) and corncob (CC) particulates in an unsaturated polyester resin (UPR) matrix. Lignocellulosic analysis revealed that GNS contains a high cellulose content (61.537%), while CC exhibits higher hemicellulose (36.434%) and oil content (8.489%), influencing mechanical strength and moisture behavior. Water absorption tests showed a progressive increase with time, with values ranging from 0.338–0.474 wt.% for 100% GNS composites and up to 1.326–1.987 wt.% for 100% CC composites after 5 hours, confirming higher hydrophilicity of CC-rich composites. Mechanical evaluation indicated an ultimate tensile strength of approximately 59 MPa, a Tensile's modulus of 7.9 GPa, and strain at break of 0.892%, demonstrating good stiffness but limited ductility. BET analysis showed a high surface area of 266.971 m²/g with a strong correlation coefficient ($r = 0.99297$), indicating significant porosity and adsorption potential. SEM analysis confirmed uniform particle dispersion with localized porosity, while EDX revealed dominant silicon content (57.0%) alongside carbon (19.5%) and oxygen (10%). FTIR spectra identified key functional groups at 665.3, 1718.3, 2871.9, and 3347.1 cm⁻¹, indicating the presence of silicate, carbonyl, alkyl, and hydroxyl groups.

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The novelty of this study lies in the hybridization of CC and GNS to achieve tunable moisture and mechanical properties. The results demonstrate the potential of agro-waste composites for sustainable structural and functional applications.

Key words: *Corn cob, groundnut shell, hybrid, composite, water absorption*

INTRODUCTION

Sustainability concerns, fossil resource depletion, and increased agricultural waste generation have intensified scientific interest in biodegradable and renewable materials for engineering applications [1].

Biomass-derived residues offer compelling substitutes for synthetic composite reinforcements due to their biodegradability, low cost, carbon neutrality, and reduced environmental footprint [2, 3]. Recent advancements in polymer bio-composites demonstrate that natural fillers can enhance specific mechanical and physical properties while promoting resource efficiency and a circular economy model [4, 5].

Agricultural residues such as corncob (CC) and groundnut shells (GNS) are widely available in developing regions, yet remain significantly underutilized [6, 7, 8, 9]. Conventional disposal through landfilling, open burning, or indiscriminate dumping contributes to environmental degradation and public health concerns [10]. Valorizing these residues into polymer composites provides an avenue for waste management and sustainable materials development [11, 12]. Corncob, a lignocellulosic by-product of maize cultivation, contains substantial cellulose fractions suitable for improving stiffness, toughness, and dimensional stability in polymer matrices [13]. Previous studies have demonstrated improvements in impact performance, toughness, thermal behavior, and weight reduction when corncob particulates are incorporated into epoxy and polypropylene composites at controlled particle sizes and loadings. Karchi et al. [6] developed sustainable epoxy composites using corncob cellulose as a reinforcement material. Kumar and Saha [13] studied the effects of particle size on structural, physical, mechanical and tribology behavior of corn cob filler-based epoxy biocomposites.

Groundnut shells also exhibit valuable lignocellulosic structures and have been integrated into natural and synthetic polymer matrices for low-cost packaging, insulation, and structural components [8, 14]. Their relatively high lignin content supports mechanical reinforcement and thermal stability, while the abundance of hydroxyl functional groups promotes interfacial interactions with epoxy systems [9, 15]. Studies exploring GNS-based composites have shown improvements in hardness, stiffness, and microstructural uniformity when used as fillers or hybrid modifiers, such as Soni et al. [16] who successfully evaluated the mechanical properties of sisal fiber and groundnut shell particulate reinforced hybrid epoxy composites. However, single-filler systems seldom provide balanced mechanical performance; instead, hybridization strategies allow engineers to tailor composite response by exploiting potential synergistic effects between multiple natural fillers.

Hybrid bio-composites represent an emerging direction in sustainable material design, wherein two or more particulate or fiber reinforcements are dispersed within a matrix to achieve optimized and multifunctional behavior [17]. Hybridization of lignocellulosic fillers can potentially enhance impact strength, stiffness, thermal stability, and weight reduction while reducing production cost relative to synthetic fiber composites [18].

Epoxy resin remains a suitable matrix for natural hybrid fillers due to its dimensional stability, strong adhesion potential, chemical resistance, and compatibility with particulate reinforcement [19].

Ramu et al. [20] studied the physic mechanical properties of Bamboo Fiber/Groundnut Shell Epoxy Hybrid Polymer Nanocomposites. Annamalai [21] studied woven ramie fibre epoxy composite with silane-treated groundnut shell powder as a filler. Merinto and Miraculas [11] developed fiberglass-reinforced hybrid epoxy composites with pineapple fiber and corn cob-derived bio silica and evaluated the performance analysis.

Despite promising developments, significant research gaps persist regarding the combined reinforcement of epoxy matrices using hybrid CC/GNS particulates. Addressing these knowledge gaps is crucial for advancing biomass-derived fillers as credible substitutes for synthetic reinforcing agents in automotive interiors, packaging materials, building components, consumer goods, and related sectors. Furthermore, systematic characterization of hybrid CC/GNS epoxy composites offers insights into how agro-waste valorization strategies can be integrated into circular economy frameworks in regions where agricultural residues are abundant and waste management infrastructure is limited.

The present study investigates the mechanical and physical performance of hybrid corncob and groundnut shell reinforced epoxy composites. Hybrid composites were fabricated using defined filler ratios and particle sizes, and subsequently evaluated in terms of tensile strength, flexural behavior, hardness, impact resistance, density, thermal characteristics, and water absorption. Particular emphasis was placed on assessing filler-matrix compatibility, hybrid synergies, and property trade-offs associated with natural particulate reinforcement. The aim of the study is to determine the suitability of corncob-groundnut shell hybrid particulate fillers for enhancing epoxy composite performance and promoting sustainable materials development. Specifically, the study seeks to (i) characterize the physical properties of CC and GNS particulates; (ii) evaluate mechanical and physical responses of epoxy composites at varying hybrid filler loadings; and (iii) establish structure-property relationships that inform future bio-composite material design.

MATERIAL AND METHODS

Materials and Equipment's

Unsaturated polyester resin (UPR) and methyl ethyl ketone peroxide (MEKP) manufactured by ebenCHEM Germany were bought from Galaxy Interiors and Epoxy venture, Abuja. Groundnut shell and corn cob were purchased from local traders in Umuahia. All the reagents and glass wares used were purchased from General Sales Organization, Chemical, Enugu, Enugu State. Fourier infrared spectrometer (Bruker Alpha I, U.S.A.), SEM/EDX machine (Hitachi TM-400) and Universal testing machine manufactured by Wincom, PR China.

Methods

Biomass Materials Preparation

Biomass materials used as composite were air dried for one week. The dried materials were crushed using milling machine.

The crushed or grinded samples were sieved using sieve size of 250 μm . This is to obtain uniform size samples with enhanced surface area. Figures 1a and 1b and 2a and 2b show the raw, grounded corn cob, raw groundnut shell and grounded groundnut shell.



Fig. 1a. Corncob



Fig. 1b. Ground Corncob



Fig. 2a. Groundnut Shell



Fig. 2b. Ground Groundnut Shell

Lignocellulose Characterization of Biomass

Groundnut shell and corn cob were characterized for lignocellulose properties. Lignocellulose characterization was done according to the method of Diaz *et al.*, (2013).

Sample de-fating (extractives): A 200 g sample was accurately weighed using an analytical balance and transferred into a 1000 mL flat-bottom flask. A sufficient volume of n-hexane was added to completely immerse the sample, followed by vigorous agitation to ensure proper solvent penetration. The flask was sealed with aluminum foil and reinforced with masking tape to minimize solvent loss and contamination. The mixture was allowed to stand for 48 h to achieve exhaustive lipid extraction. Thereafter, the n-hexane containing dissolved oil was carefully decanted, and the defatted sample was air-dried at ambient temperature. The fat content was calculated using Equation (1):

$$\text{Fat \%} = [(\text{Initial wt. of sample} - \text{Final wt. of sample}) / \text{Initial wt. of sample}] \times 100 \quad (1)$$

Bleaching (lignin removal): The defatted sample was transferred into a three-neck round-bottom flask, and 500 mL of 7.5% (w/v) aqueous hydrogen peroxide (H_2O_2) solution was added. A reflux condenser was fitted to the central neck, and the system was heated at 90 °C for 2 h to facilitate lignin removal. Continuous cooling water was circulated through the condenser jacket to prevent solvent loss. After refluxing, the mixture was cooled, filtered under vacuum, and washed thoroughly with hot distilled water to neutralize residual chemicals. The sample was then air-dried. The lignin content was determined using Equation (2):

$$\text{Lignin \%} = [(\text{Initial wt. from lignin removal} - \text{Final wt.}) / \text{Initial wt.}] \times 100 \quad (2)$$

Sodium hydroxide treatment (hemicellulose removal): The bleached sample was treated with 500 mL of 18% sodium hydroxide (NaOH) solution in a flat-bottom flask and stirred at room temperature for 30 min. The flask was covered with aluminum foil to prevent contamination. The mixture was subsequently filtered under vacuum and washed with 500 mL of 20% acetic acid solution in hot water to neutralize residual alkali. Further washing with hot distilled water was carried out until a neutral pH was confirmed using a pH meter. The residue was then dried at ambient conditions. Hemicellulose content was determined using Equation (3):

$$\text{Hemicellulose \%} = [(\text{Initial wt.} - \text{Final wt.}) / \text{Initial wt.}] \times 100 \quad (3)$$

Total ash and cellulose: A clean, dry porcelain crucible (w_1) was weighed, after which 2 g of the sample (w_2) was introduced. The crucible was heated in a furnace at 600 °C for 3 h to ensure complete combustion of organic matter. It was then cooled in a desiccator and reweighed (w_3). Ash content was calculated using Equation (4), while cellulose content was obtained by difference using Equation (5):

$$\text{Ash \%} = [(\text{Sample weight } w_2 - \text{Weight loss } w_2) / w_2] \times 100 \quad (4)$$

$$\text{Cellulose \%} = 100 - (\text{Fat} + \text{Lignin} + \text{Hemicellulose} + \text{Ash}) \quad (5)$$

Composite Formulation

Corncob (CC) and groundnut shell (GNS) particulates with an average particle size of 250 μm were used as reinforcing phases, while unsaturated polyester resin served as the matrix material. The required proportions of reinforcement and matrix, as specified in the experimental design (Tab. 1), were measured and mixed thoroughly in a 500 mL beaker to ensure uniform dispersion. Following homogenization, 5 wt.% of methyl ethyl ketone peroxide (MEKP) was added as a curing agent (hardener), and the mixture was further stirred to initiate crosslinking. Composite fabrication was carried out using the hand lay-up technique [2]. The mixture was poured into glass molds and allowed to cure at room temperature ($\approx 30^\circ\text{C}$). The molded composites were left undisturbed in a fume hood for 24 h to ensure complete curing and volatilization of residual compounds. Subsequently, the cured composites were demolded and wrapped in polyethylene bags for storage and further characterization. The process flow diagram of the composite fabrication is presented in Fig. 3.

Tab.1. Composite formulation

S/N	Groundnut (wt.%)	Corn cob (wt.%)	UPR (wt.%)	MEKP (wt.%)
1	25.00	0	70.00	5
2	22.50	2.50	70.00	5
3	20.00	5.00	70.00	5
4	17.50	7.50	70.00	5
5	15.00	10.00	70.00	5
6	12.50	12.50	70.00	5
7	10.00	15.00	70.00	5
8	7.50	17.50	70.00	5
9	5.00	20.00	70.00	5
10	2.50	22.50	70.00	5
11	0.00	25.00	70.00	5



Fig. 3. Flowchart of Developed Composite (Groundnut shell and Corncob)

Water Uptake Test

The composites were cut to a small dimension ($10 \times 2 \times 0.2$ cm) for the water uptake test. The composite samples were submerged in a beaker holding 1000 mL of distilled water at room temperature for various periods (1 h, 2 h, 3 h, 4 h and 5 h). Samples were removed from the beaker, and the water uptake of the composites was calculated using the initial and final weights. The water uptake was determined by applying Equation (6):

$$\text{Water uptake \%} = [(\text{Final weight} - \text{Initial weight}) / \text{Initial weight}] \times 100 \quad \dots\dots (6)$$

Characterization of the Composite

The sample was characterized for the presence of functional groups using Fourier Transform Infrared Spectrometry. Surface morphology and elemental analysis was done using scanning electron microscopy and energy dispersive X-ray spectroscopy. Tensile strength, tensile modulus and hardness were analyzed using universal testing machine.

Hardness Test

The reference standard for this test method is ASTM E92. Hardness of a material is its capacity to resist indentation. This test method is applicable to metals and uses a test force between 1 gf to 120 kgf. For accurate test results, the hardness reading has to be taken on a flat specimen.

To prepare the metal sample for analysis, the surface of the sample is initially polished using diamond paste. The sample is cleaned between stages to prevent contamination.

For the sample testing, the diamond indenter is brought into contact perpendicular to the sample and the force (f) is applied. The time for the initial application of the force to the full test force should not be more than 10 seconds. The full test force should be applied for 10 to 15 seconds. The length of the 2 diagonals of indentation are measured and the mean diagonal length is calculated. Hardness is calculated using Equations (7) and (8):

$$HV = \text{Test Force} / \text{Surface Area} = F(\text{kgf}) / A(\text{mm}^2) \quad \dots\dots\dots (7)$$

$$HV = 1.8544 \times F(\text{kgf}) / d^2(\text{mm}^2) \quad \dots\dots\dots (8)$$

Tensile Strength Determination

Tensile strength testing follows ASTM A370-21 standards for steel products. The sample's longitudinal direction is verified, then cut (~200 mm × 50 mm) and milled to achieve the required gauge length, fillet radius (≥ 13 mm), and gripping sections (≥ 50 mm). Testing is performed using a controlled rate, initially linear per Hooke's law, with stress proportional to strain. Yield strength is determined via the 0.2% offset method, after which the extensometer is removed. Strain hardening and necking occur until failure. Tensile strength is calculated as maximum load divided by cross-sectional area. Elongation and percentage reduction in area quantify ductility.

RESULTS AND DISCUSSION

This section presents the results of the composite material characterization, including Lignocellulose characterization, Water Uptake, Tensile strength, Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM) and Brunauer-Emmett-Teller (BET) analysis.

Lignocellulose Characterization Results

The lignocellulose characterization results for corncob and groundnut shell are presented in Tab. 2.

Tab.2. Lignocellulose characterization of corncob and groundnut shell

Sample	Moisture (%)	Lignin (%)	Hemicellulose (%)	Ash (%)	Oil (%)	Cellulose (%)
Corn cob	3.461	19.189	36.434	1.642	8.489	30.785
Groundnut shell	0.954	17.926	13.602	5.292	0.689	61.537

The results presented in Tab. 2 indicate that groundnut shell (GNS) possesses a higher cellulose content (61.537%) compared to corncob (CC) (30.785%), suggesting its potential as a superior reinforcing agent for bio composite materials due to enhanced mechanical strength and stiffness.

Conversely, corncob exhibits a higher hemicellulose content (36.434%) and oil content (8.489%), which may influence its moisture uptake and dimensional stability. These compositional differences provide a basis for tailoring biocomposite properties through hybridization of CC and GNS fibers to achieve a balanced combination of stiffness, flexibility, and stability. The lignocellulosic composition critically affects composite performance. Higher cellulose in GNS contributes to increased rigidity and tensile strength, while elevated hemicellulose in CC may enhance flexibility but also promote moisture absorption, potentially affecting dimensional stability. Lignin content, comparable in both materials, imparts thermal stability, and the biodegradable nature of these fibers enhances environmental sustainability. Understanding the lignocellulose profiles of CC and GNS is therefore essential for designing bio composites with optimized properties for targeted applications. These findings are consistent with previous studies [22, 23, 24].

Fibre Water Uptake Analysis

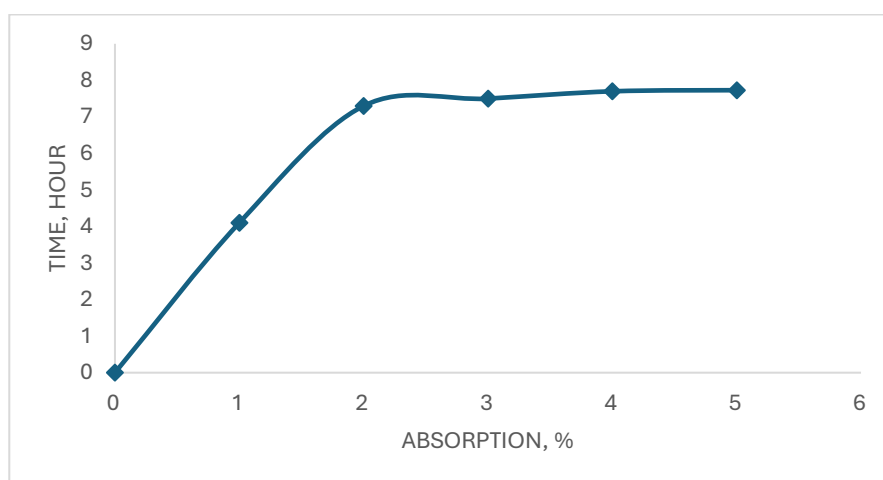


Figure 4. Graph of Groundnut shell vs Water uptake

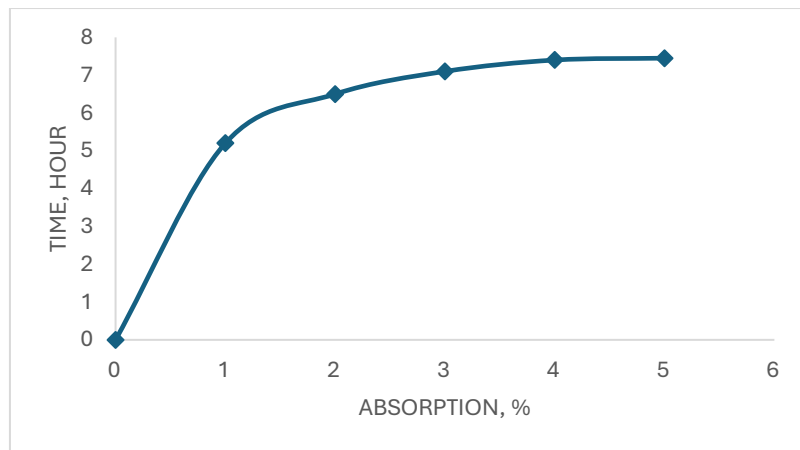


Figure 5. Graph of Corn cob vs Water uptake

The water uptake analysis for groundnut shell and corn cob is shown in Figs. 4 and 5 respectively. Water absorption increased rapidly during the initial immersion period due to capillary penetration of water into fibre lumens and surface pores. As time progressed, the rate of absorption declined and approached equilibrium, indicating saturation of accessible hydroxyl sites and diffusion limitations within the fibre cell wall. This behavior is consistent with Fickian diffusion commonly reported for lignocellulosic fibres, where the absorption curve exhibits an initial linear region followed by a plateau corresponding to equilibrium moisture content. This observation aligns with the findings of Daramola *et al.* [25], Bone *et al.* [26] and Prasad *et al.* [27].

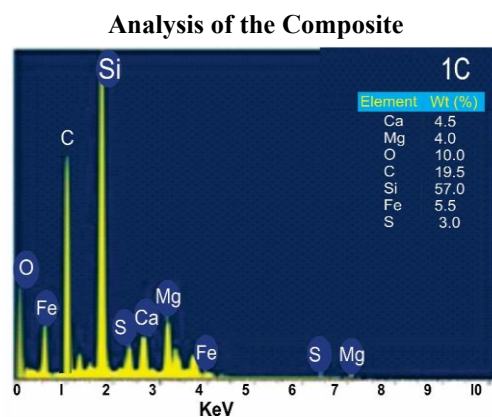
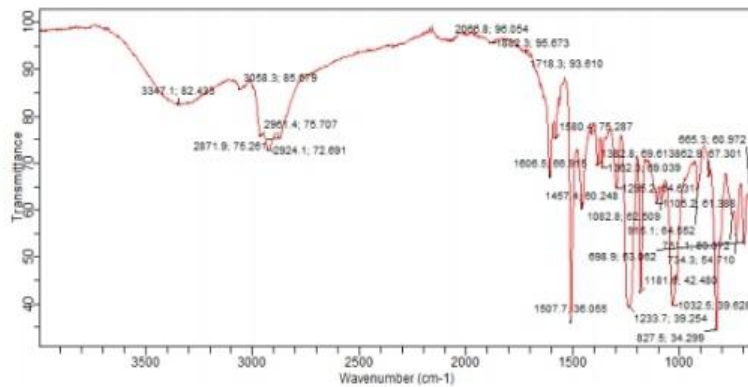


Fig. 6. Groundnut shell / corn cob hybrid composite

Tab. 3 presents the water uptake results for various composite formulations with different ratios of groundnut shell (G. nut) and corncob (C. cob) in an unsaturated polyester resin (UPR) matrix with a fixed amount of METP. Fig. 6 shows the developed hybrid composite.

Tab. 3. Water uptake analysis of the developed hybrid composite

S/N	G. nut (wt.%)	C. cob (wt.%)	UPR (wt.%)	METP (wt.%)	Water uptake (wt.%)				
					1 hr.	2 hr.	3 hr.	4 hr.	5 hr.
1	25.00	0	70.00	5	0.338	0.356	0.410	0.446	0.474
2	22.50	2.50	70.00	5	0.379	0.437	0.573	0.673	0.744
3	20.00	5.00	70.00	5	0.399	0.479	0.637	0.723	0.782
4	17.50	7.50	70.00	5	0.422	0.544	0.784	0.844	0.939
5	15.00	10.00	70.00	5	0.617	0.788	0.913	0.897	1.094
6	12.50	12.50	70.00	5	0.793	0.845	0.975	1.039	1.275
7	10.00	15.00	70.00	5	0.916	0.959	1.184	1.316	1.312
8	7.50	17.50	70.00	5	0.979	0.992	1.202	1.420	1.599
9	5.00	20.00	70.00	5	0.994	1.1975	1.278	1.617	1.718
10	2.50	22.50	70.00	5	1.073	1.383	1.544	1.755	1.833
11	0.00	25.00	70.00	5	1.326	1.529	1.887	1.920	1.987



In contrast, composites with higher groundnut shell content showed lower water absorption, likely due to their relatively higher cellulose crystallinity and more compact microstructure, which limits water penetration. The significant disparity between the 100% corncob and 100% groundnut shell composites underscores the strong influence of material composition on moisture behavior.

These findings have important implications for practical applications. Composites rich in corncob may be suitable for moisture-absorbing applications such as agriculture, biomedical systems, and water treatment, while groundnut shell-rich composites are better suited for applications requiring dimensional stability and moisture resistance, including packaging and footwear. Overall, this study highlights the potential of agricultural waste-based composites for tailored performance and sustainable material development [28, 29, 30].

SEM Analysis

At 8000 $\times$ magnification (Fig. 8), the SEM micrograph reveals the surface morphology of the developed composite, clearly showing the distribution of groundnut shell and corncob particles within the matrix.

The image indicates a relatively uniform dispersion of the reinforcing particles, suggesting good interfacial adhesion between the groundnut shell and corncob phases. Such uniformity is essential for effective stress transfer and improved composite performance. The morphological characterization was carried out at magnifications of 8000 $\times$ and 10000 $\times$ (Figs. 8 and 9, respectively). The micrographs generally exhibit a rough and heterogeneous surface with compacted regions, indicative of a relatively dense structure. However, the presence of visible gaps and voids in certain regions suggests localized porosity, which may serve as potential sites for stress concentration and crack initiation. At higher magnification (Fig. 9), the SEM image provides detailed insight into particle morphology, including surface texture, size variation, and the interaction between fibrous and particulate constituents. Overall, the SEM analysis confirms that the composite exhibits a heterogeneous yet reasonably well-bonded microstructure [31, 32, 33].

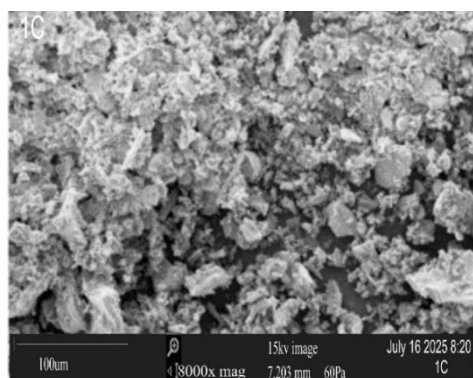


Fig. 8. SEM of the composite (8.000 $\times$)

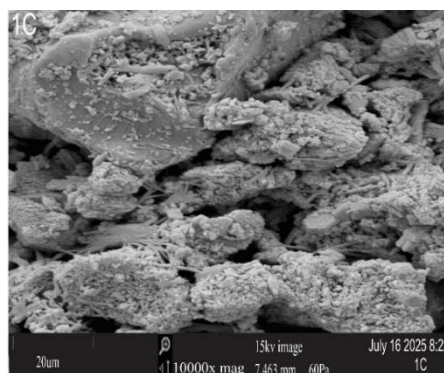


Fig. 9. SEM of the composite (10.000 $\times$)

Fibre Water Uptake Analysis

Elemental Composition (EDX) Analysis

The energy-dispersive X-ray (EDX) analysis of the composite, as presented in Fig. 10, reveals that the material is predominantly composed of silicon (57.0%), followed by carbon (19.5%) and oxygen (10%). Minor constituents include iron (5.5%), calcium (4.5%), magnesium (4.0%), and sulfur (3.0%). The high silicon content is indicative of enhanced thermal stability, hardness, and durability, which are desirable for structural and high-temperature applications. Carbon contributes to improved mechanical strength, while oxygen is associated with oxide formation and surface functional groups that influence interfacial interactions and chemical reactivity. The interaction and distribution of these elements within the composite matrix play a critical role in determining its mechanical, thermal, and physicochemical properties [34, 35, 36].

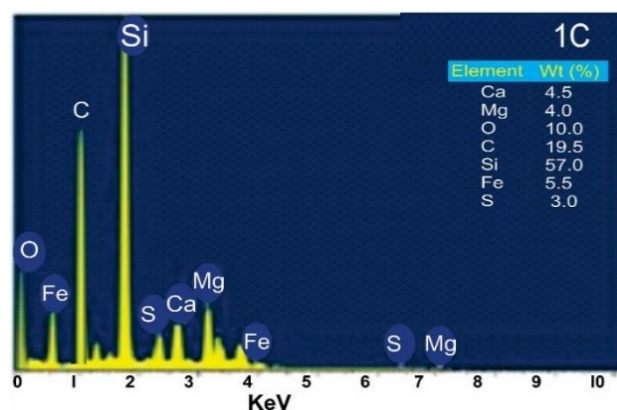


Fig. 10. EDX of the composite

FTIR Analysis

The Fourier Transform Infrared (FTIR) analysis of the produced composite, as presented in Fig. 11, provides insight into the functional groups responsible for its physicochemical behavior, including its relatively low water uptake characteristics. The identified absorption peaks, summarized in Tab. 4, confirm the presence of key functional groups within the composite matrix. The absorption band at 665.3 cm^{-1} is attributed to C–H bending or Si–O stretching vibrations, indicating the presence of organic constituents and possible silicate structures. The peak observed at 1718.3 cm^{-1} corresponds to C=O stretching vibrations, confirming the presence of carbonyl functional groups. The band at 2871.9 cm^{-1} is associated with C–H stretching of aliphatic (alkyl) groups, reflecting the organic backbone of the composite material. Furthermore, the broad absorption peak at 3347.1 cm^{-1} is assigned to O–H stretching vibrations, indicating the presence of hydroxyl groups.

Overall, the FTIR results confirm the coexistence of organic and inorganic functional groups within the composite, contributing to its structural integrity and moisture resistance [37, 38].

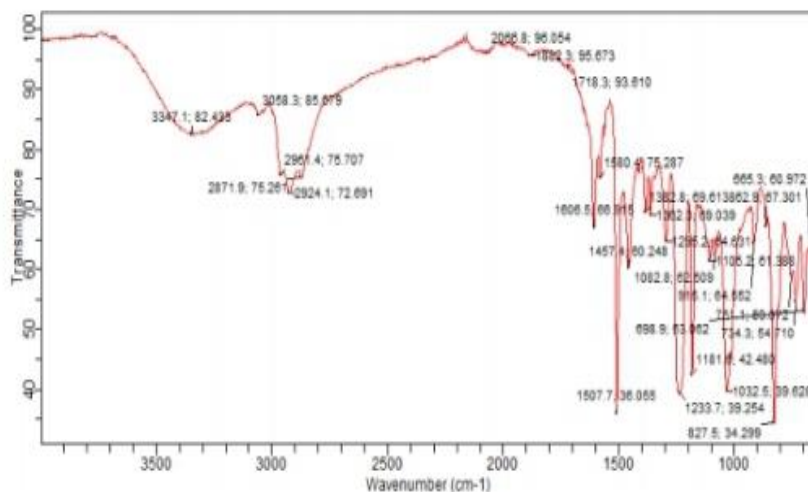


Fig. 11. Image of FTIR Spectra Analysis – see original figure

Tab. 4 Peak Assignments

Wavenumber (cm ⁻¹)	Intensity	Possible Assignment
665.3	60.972	C-H bending or Si-O stretching
1718.3	93.610	C=O stretching
2871.9	75.261	C-H stretching
3347.1	82.433	O-H stretching

The presence of relatively hydrophobic functional groups, such as C–H and C=O, contributes significantly to the reduced water uptake observed in the composite. Although hydroxyl (O–H) groups are present and can facilitate some degree of water interaction due to their hydrophilic nature, their overall effect is moderated by the composite's structure and the dominance of less polar functional groups. This controlled water absorption behavior suggests that the composite may be suitable for applications requiring water resistance or reduced moisture sensitivity, such as protective materials, packaging, or structural components exposed to humid environments.

BET Analysis

The results are presented in Tab. 5 below.

Tab. 5 BET Results

Parameter	Value
Surface area	266.971 m ² /g
Correlation coefficient (r)	0.99297
C constant	2.801
Slope	8.388
Intercept	4.657

The BET analysis shown in Tab. 5 revealed a high surface area of 266.971 m²/g, which can impact its adsorption properties, reactivity, and interactions with its environment.

The correlation coefficient (r) of 0.99297 suggests a strong linear relationship between the data points, providing a valuable insight into the surface area and porosity of the composite material. This finding aligns with the observations of Ravi and Thyagarajan [39], Farghaly *et al.* [40] and Salama *et al.* [41].

Tensile Strength Analysis

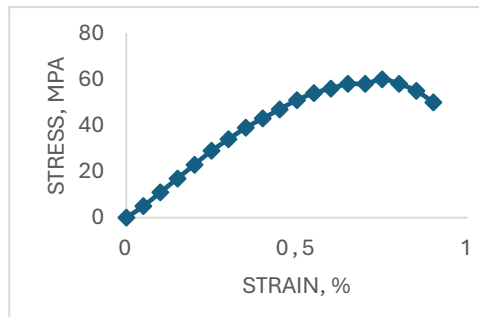


Figure 12. Graphical Representation of Tensile Strength

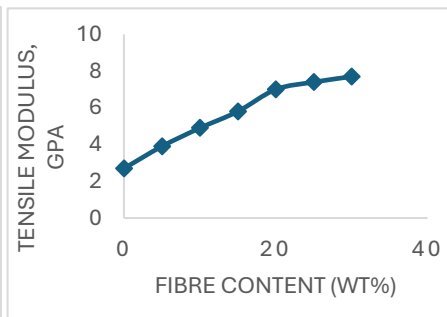


Figure 13. Graphical Representation of Tensile modulus

The tensile stress–strain response of the hybrid composite in Fig. 12 showed a distinct initial linear elastic region, reflecting efficient load transfer between the reinforcing fibres and the polymer matrix and indicating good interfacial bonding at low strain levels. The composite exhibited an ultimate tensile strength of approximately 59 MPa, a strain at break in the range of 0.892%, and a Young's modulus of 7.9 GPa (Fig. 13), confirming a relatively stiff material with limited ductility. As the strain increased, a gradual departure from linearity was observed, attributed to the initiation of matrix microcracks and progressive interfacial debonding between fibre and matrix.

The tensile strength achieved suggests a positive hybridization effect, arising from the complementary mechanical contributions of the different reinforcing phases, while the low elongation at break is consistent with the predominantly brittle fracture mechanism commonly reported for structural polymer composites [42, 43, 44].

The predicted tensile modulus values show a progressive increase with fibre loading, reflecting the increasing contribution of the reinforcing phase to the overall stiffness of the composite. As the reinforcement level increases further, the rate of improvement becomes more gradual. At higher fibre fractions, the predicted modulus approaches a plateau, indicating that additional reinforcement contributes less effectively to stiffness enhancement. This reduction in marginal gain can be attributed to factors such as fibre–fibre interaction, localized agglomeration, and constraints in matrix wetting, all of which reduce the effectiveness of load transfer. Overall, the predicted trend aligns with established composite theory [44, 45].

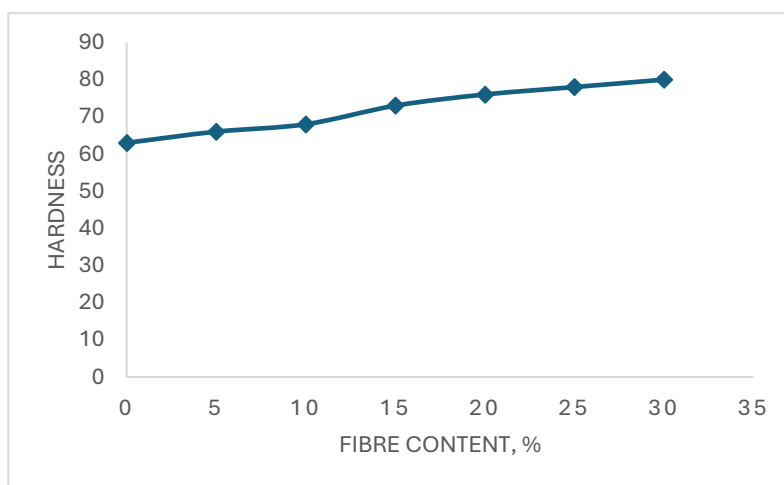


Fig. 14. Graphical Representation of Hardness Test – see original figure

The hardness graph in Fig. 14 shows a steady increase with increasing fibre content, reflecting the growing contribution of the reinforcing phase to the composite's resistance against surface indentation.

At relatively low fibre loadings, the improvement in hardness arises from the restriction of matrix chain mobility and the enhanced resistance to localized plastic deformation under the indenter. At higher loadings, particularly beyond about 25 wt.%, the rate of increase diminishes and approaches a plateau. This trend is commonly observed in fibre-reinforced composites, where excessive reinforcement may lead to fibre agglomeration, reduced matrix continuity, and localized interfacial defects that limit further improvement in surface resistance [46, 47].

CONCLUSIONS

This study successfully developed and characterized hybrid groundnut shell–corncob reinforced polyester composites with tailored properties. The results demonstrate that material performance is strongly dependent on filler composition. Groundnut shell, with its high cellulose content, contributed significantly to improved stiffness, reduced water absorption, and enhanced dimensional stability. In contrast, corncob increased porosity and hydrophilicity, leading to higher water uptake but offering advantages in applications requiring permeability or adsorption. The mechanical properties, including a tensile strength of approximately 59 MPa and modulus of 7.9 GPa, confirm that the hybrid composites possess adequate strength and rigidity for structural applications. SEM analysis revealed good interfacial bonding and uniform dispersion, although some voids were observed, which may influence long-term durability. EDX and FTIR analyses confirmed the presence of functional groups and elements responsible for the composite's mechanical, thermal, and chemical behavior. Additionally, the high BET surface area (266.971 m²/g) highlights the material's suitability for adsorption-related applications. Overall, the study establishes that hybridization of agricultural residues can effectively balance mechanical strength, moisture resistance, and functional performance, providing a sustainable alternative to conventional composites. Further studies should optimize the CC/GNS ratio to achieve an ideal balance between mechanical strength and water resistance, particularly for structural applications.

REFERENCES

- [1] Sarmin, S. N., Jawaaid, M., Mahmoud, M. H., Saba, N., Fouad, H., Alothman, O. Y., Santulli, C. 2024. Mechanical and physical properties analysis of olive biomass and bamboo reinforced epoxy-based hybrid composites. *Biomass Conversion and Biorefinery*, 14(6), pp.7959-7969.
- [2] Kumar, B., Adil, S., Kim, J. 2026. Biomass-derived epoxy resin and its application for high-performance natural fiber composites. *Journal of Reinforced Plastics and Composites*, 45(1-2), pp. 208-221.
- [3] Choudhary, M., Singh, D., Jain, S. K., Singh, D., Devnani, G. L., Singh, S., Kumar, M. 2023. Thermal and mechanical investigation of chemically treated hybrid biomass epoxy bio-composite: an approach of pyrolysis kinetics. *Bioresource Technology Reports*, 23, 101589.
- [4] Jia, P., Ma, Y., Kong, Q., Xu, L., Li, Q., Zhou, Y. 2020. Progress in development of epoxy resin systems based on biomass resources. *Green Materials*, pp. 8(1), 6-23.
- [5] Ganapathy, T., Ramasamy, K., Suyambulingam, I., Siengchin, S. 2024. Synergetic effect of graphene particles on novel biomass-based *Ficus benghalensis* aerial root/flax fiber-reinforced hybrid epoxy composites for structural application. *Biomass Conversion and Biorefinery*, 14(17), pp. 20713-20750.
- [6] Karchi, V. P., Umarfarooq, M. A., Chikkatti, B. S., Achappa, S., Ashwini, M., Banapurmath, N. R., Sajjan, A. M. 2025. Sustainable epoxy composites: corncob cellulose as a reinforcement material. *Cellulose*, 32(15), pp. 8987-9000.
- [7] Kumar, K. S., Srinivasan, R. G., Palani, S., Čep, R., Salunkhe, S., Nasr, E. A. 2025. Mechanical characterization of sisal fiber-groundnut shell powder reinforced epoxy composites. *Scientific Reports*, 15(1), pp.33149.
- [8] Kisan, U., Dubey, V., Sharma, A. K., Mital, A. 2021. Synthesis of groundnut shell/rice husk hybrid composite—a review. *IOP Conference Series: Materials Science and Engineering*, 1116(1), pp. 012001-012013.

- [9] Patnaik, P. K., Mishra, S. K., Swain, P. T. R., Sameer, Panda, D. 2022. Effect of groundnut shell particulate content on physical and mechanical behavior of jute-epoxy hybrid composite. *Journal of The Institution of Engineers (India): Series E*, 103(1), pp. 65-72.
- [10] Jia, P., Ma, Y., Kong, Q., Xu, L., Li, Q., Zhou, Y. 2020. Progress in development of epoxy resin systems based on biomass resources. *Green Materials*, 8(1), pp. 6-23.
- [11] Merinto, P. A. P., Antony Miraculas, G. 2025. Characterization of fiberglass-reinforced hybrid epoxy composites with pineapple fiber and corn cob-derived biosilica. *Composite Interfaces*, pp.1-15.
- [12] Stanescu, M. M., Bolcu, D., Miritoiu, C. M., Ciuca, I., Bolcu, A., Radoi, I. A. 2024. The Study of Mechanical Properties of Sandwich Composites with a Hybrid Resin Matrix Based on Dammar, a Core of Chopped Corn Cobs and Natural Fabric Faces. *Materiale Plastice*, 61(3) pp. 61-68.
- [13] Kumar, S., Saha, A. 2022. Effects of particle size on structural, physical, mechanical and tribology behaviour of agricultural waste (corn cob micro/nano-filler) based epoxy biocomposites. *Journal of Material Cycles and Waste Management*, 24(6), pp. 2527-2544.
- [14] Ramu, S., Senthilkumar, N., Deepanraj, B. 2023. Experimental investigation on alkali treated (NaOH) groundnut shell (*Arachis hypogaea* L.) and rice husk (*Oryza sativa*) particle epoxy hybrid composites. *Materials Today: Proceedings*. pp. 3-8.
- [15] Deepak Suresh Kumar, R., Gurusamy, P., Dinesh, D. 2024. Hybrid effect of neem seed and groundnut shell bio-fillers on the mechanical, water absorption and thermal properties of jute fiber reinforced epoxy composites. *International Journal of Materials Research*, 115(7), pp. 517-528.
- [16] Soni, C., Patnaik, P. K., Mishra, S. K., Panda, S. S., Rath, K. C. 2023. Sisal fiber and groundnut shell particulate reinforced hybrid epoxy composites: A study on mechanical and tribological properties. *Materials Today: Proceedings*. pp. 13-22.
- [17] Ilyas, R. A., Zuhri, M. Y. M., Norrahim, M. N. F., Misenan, M. S. M., Jenol, M. A., Samsudin, S. A., Omran, A. A. B. 2022. Natural fiber-reinforced polycaprolactone green and hybrid biocomposites for various advanced applications. *Polymers*, 14(1), pp. 182- 192.
- [18] Elmasry, A., Azoti, W., Ghoniem, E., Elmarakbi, A. 2024. Modelling of hybrid biocomposites for automotive structural applications. *Composites Science and Technology*, 251, 110562, pp. 23-34.
- [19] Adediran, A. A., Akinwande, A. A., Balogun, O. A., Bello, O. S., Akinbowale, M. K., Adesina, O. S., Ojo, A. A. 2022. Mechanical and optimization studies of polypropylene hybrid biocomposites. *Scientific Reports*, 12(1), pp. 2468- 2476.
- [20] Ramu, S., Senthilkumar, N., Rajendran, S., Deepanraj, B., Abdeta, D. B. 2022. Physical and Mechanical Characterization of Bamboo Fiber/Groundnut Shell/Copper Particle/MWCNT-Filled Epoxy Hybrid Polymer Nanocomposites. *Journal of Nanomaterials*, 2022(1), pp. 3026881- 3026892.
- [21] Annamalai, S. B. 2023. Experimental study on woven ramie fibre epoxy composite with silane-treated groundnut shell powder as a filler material. *Transactions of FAMENA*, 47(1), pp. 1-12.
- [22] Mary Onyelucheya, C., Tagbo Nwabanne, J., Olawale Daramola, M., Ayodele Iwarere, S. 2024. Chemical, thermogravimetric and elemental characterization of Nigerian groundnut and cowpea shells for sustainable valorization. *IOP Conference Series: Earth and Environmental Science*, 1322(1), pp. 012003-012019.
- [23] Priyadharsini, R., Balavijayalakshmi, J. 2025. High-performance symmetric supercapacitor using triple biowaste-derived activated carbon: groundnut shell, sugarcane and corn cob residues. *Ionics*, pp. 1-12.
- [24] Tikhe, K., Nadupuru, S. R. 2024. Lignocellulosic valorization of groundnut shells for bioethanol: Energy potential and techno-economic feasibility. *Maejo International Journal of Energy and Environmental Communication*, 6(3), pp. 40-49.

- [25] Daramola, O. O., Akinwekomi, A. D., Adediran, A. A., Akindote-White, O., Sadiku, E. R. 2019. Mechanical performance and water uptake behaviour of treated bamboo fibre-reinforced high-density polyethylene composites. *Heliyon*, 5(7) pp. 23-30.
- [26] Bone, J. E., Sims, G. D., Maxwell, A. S., Frenz, S., Ogin, S. L., Foreman, C., Dorey, R. A. 2022. On the relationship between moisture uptake and mechanical property changes in a carbon fibre/epoxy composite. *Journal of Composite Materials*, 56(14), pp. 2189-2199.
- [27] Prasad, V., Joseph, M. A., Sekar, K. 2018. Investigation of mechanical, thermal and water absorption properties of flax fibre reinforced epoxy composite with nano TiO₂ addition. *Composites part A: Applied science and manufacturing*, 115, pp.360-370.
- [28] Abd Halip, J., Hua, L. S., Ashaari, Z., Tahir, P. M., Chen, L. W., Uyup, M. K. A. 2019. Effect of treatment on water absorption behavior of natural fiber-reinforced polymer composites. In *Mechanical and physical testing of biocomposites, fibre-reinforced composites and hybrid composites* (pp. 141-156). Woodhead Publishing.
- [29] Haque, M. S., Ovi, I. A., Prome, F. S., Hossain, A. 2023. Impact of water absorption on tensile strength: a comparative study of jute fiber composites with various fiber content. *Malaysian Journal on Composites Science and Manufacturing*, 12(1), pp. 114-124.
- [30] Oyewo, A. T., Oluwole, O. O., Ajide, O. O., Omoniyi, T. E., Hamayun, M. H., Hussain, M. 2022. Experimental and theoretical studies to investigate the water absorption behavior of carbon/banana fibre hybrid epoxy composite. *Materials Chemistry and Physics*, 285, pp. 126084-126094.
- [31] Zhang, P. X., Xu, W. M., Zeng, M., Lei, Y. S., Yan, H. 2022. Regulating microstructure, mechanical properties and electrochemical characteristic of 2024-CNTs aluminum composites via decorating nano Ni on the surface of CNTs. *Diamond and Related Materials*, 126, pp. 109132- 109143.
- [32] Vincent, V. A., Kailasanathan, C., Shanmuganathan, V. K., Kumar, J. S. P., Arun Prakash, V. R. 2022. Strength characterization of caryota urens fibre and aluminium 2024-T3 foil multi-stacking sequenced SiC-toughened epoxy structural composite. *Biomass Conversion and Biorefinery*, 12(9), pp.4009-4019.
- [33] Ghaib, M., Shateri, M., Thomson, D., Svecova, D. 2024. Comparison between microstructural analysis of GFRP and CFRP rebars using micro computed tomography (μ CT), scanning electron microscope (SEM), and acoustic emission (AE) techniques. *Composites Science and Technology*, 250, pp.110545-110556.
- [34] Guyett, P. C., Chew, D., Azevedo, V., Blennerhassett, L. C., Rosca, C., Tomlinson, E. 2024. Optimizing SEM-EDX for fast, high-quality and non-destructive elemental analysis of glass. *Journal of Analytical Atomic Spectrometry*, 39(10), pp. 2565-2579.
- [35] Sevimoğlu, O., Sömek, Ö. Ö., Yıldız, F. 2024. Comparative determination of the time-dependent accumulation of metal oxides in the landfill gas combustion chamber deposits using SEM-EDS, XRF and ICP OES. *Microchemical Journal*, 207, pp. 112042- 112053.
- [36] Piergiovanni, M., Mattarozzi, M., Verleysen, E., Siciliani, L., Suman, M., Bianchi, F., Careri, M. 2024. The Combined ICP-MS, ESEM-EDX, and HAADF-STEM-EDX Approach for the Assessment of Metal Sub-Micro-and Nanoparticles in Wheat Grain. *Molecules*, 29(13), pp.3148-3159.
- [37] Obaid, A. N., Al-Bermany, E. 2024. Impact of graphene nanosheets on adhesion and corrosion performance of reinforced polyurethane coating for aerospace aluminium alloy 2024-T3. *International Journal of Adhesion and Adhesives*, 132, pp. 103695-103703.
- [38] Bhuiyan, M. H. R., Liu, L., Samaranayaka, A., Ngadi, M. 2024. Prediction of pea composites physicochemical traits and techno-functionalities using FTIR spectroscopy. *LWT*, 208, pp.116667-116678.
- [39] Ravi, G., Thyagarajan, K. 2024. CoFe₂O₄/NiFe₂O₄/CeO₂ nanocomposites: structural, FTIR, XPS, BET, and magnetic properties. *Applied Physics A*, 130(10), pp. 726-741.

- [40] Farghaly, A., Maher, E., Gad, A., El-Bery, H. 2024. Synergistic photocatalytic degradation of methylene blue using TiO₂ composites with activated carbon and reduced graphene oxide: a kinetic and mechanistic study. *Applied Water Science*, 14(10), pp. 228-241.
- [41] Salama, R. S., Gouda, M. S., Aboud, M. F. A., Alshorifi, F. T., El-Hallag, A. A., Badawi, A. K. 2024. Synthesis and characterization of magnesium ferrite-activated carbon composites derived from orange peels for enhanced supercapacitor performance. *Scientific Reports*, 14(1), pp. 8223- 8236.
- [42] Yuan, M., Wu, J., Meng, Q., Zhang, C., Mao, X., Huang, S., Wang, S. 2022. The Role of Al₄C₃ morphology in tensile properties of carbon fiber reinforced 2024 aluminum alloy during thermal exposure. *Materials*, 15(24), pp. 8828-8838.
- [43] Ashwath, P., Anthony Xavier, M. 2019. Compression and diametral tensile strength analysis of graphene–Al₂O₃ reinforced AA 2024 and AA 2219 hybrid nanocomposites. In *Advances in Micro and Nano Manufacturing and Surface Engineering: Proceedings of AIMTDR 2018* (pp. 19-32). Springer Singapore.
- [44] Yang, H., Tian, S., Gao, T., Nie, J., You, Z., Liu, G., Liu, X. 2019. High-temperature mechanical properties of 2024 Al matrix nanocomposite reinforced by TiC network architecture. *Materials Science and Engineering: A*, 763, pp. 138121-138134.
- [45] Ghamkhar, G., Johari, M. S., Bodaghi, M. 2024. Enhancing damage resistance in tubular triaxial hybrid braided composites: Innovative production and tensile modulus prediction with damage analysis. *Polymer Composites*, 45(9), pp.8119-8132.
- [46] Solairaju, J. A., Rathinasamy, S., Thanikodi, S. 2024. Modeling for predicting and optimizing of the flexural and hardness properties of jute/kenaf/glass fiber nano-composite through RSM. *Results in Engineering*, 24, pp.102977-102989.
- [47] Kumar, K. S. R., Ratnam, C., Nagababu, B. 2019. Fabrication and mechanical behavior of Al 2024-B₄C MMCs and Al 2024-B₄C-GR hybrid MMCS through powder metallurgy technique. *Materials Today: Proceedings*, 18, pp.219-229.

PROCENA FIZIČKO-MEHANIČKIH I HEMIJSKIH SVOJSTAVA HIBRIDNOG KOMPOZITA NA BAZI OKLASKA KUKURUZA I LJUSKE KIKIRIKIJA

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Apstrakt. Ovaj rad istražuje razvoj i osobine održivih hibridnih biokompozita ojačanih česticama ljuske kikirikija (GNS) i oklaska kukuruza (CC) u matrici od nezasićene poliestarske smole (UPR).

Analiza lignoceluloznog sastava pokazala je da ljuska kikirikija sadrži visok udeo celuloze (61,537%), dok oklasak kukuruza ima veći sadržaj hemiceluloze (36,434%) i ulja (8,489%), što značajno utiče na mehaničku čvrstoću i ponašanje materijala pri apsorpciji vlage.

Ispitivanja upijanja vode pokazala su postepeno povećanje apsorpcije tokom vremena, pri čemu su vrednosti za kompozite sa 100% ljuske kikirikija iznosile od 0,338 do 0,474 mas.%, dok su za kompozite sa 100% oklaska kukuruza dostigle 1,326–1,987 mas.% nakon 5 časova, potvrđujući izraženiju hidrofilnost kompozita sa većim udelom oklaska kukuruza.

Mehanička ispitivanja pokazala su krajnju zateznu čvrstoću od približno 59 MPa, modul elastičnosti pri zatezanju od 7,9 GPa i relativno izduženje pri lomu od 0,892%, što ukazuje na dobru krutost, ali ograničenu duktilnost materijala.

BET analiza pokazala je veliku specifičnu površinu od 266,971 m²/g uz visok koeficijent korelacije ($r = 0,99297$), što ukazuje na značajnu poroznost i potencijal za adsorpciju. SEM analiza potvrdila je ravnomernu raspodelu čestica uz prisustvo lokalizovane poroznosti, dok je EDX analiza pokazala dominantan sadržaj silicijuma (57,0%), uz ugljenik (19,5%) i kiseonik (10%). FTIR spektri identifikovali su karakteristične funkcionalne grupe pri talasnim brojevima 665,3, 1718,3, 2871,9 i 3347,1 cm⁻¹, što ukazuje na prisustvo silikatnih, karbonilnih, alkilnih i hidroksilnih grupa.

Naučna novina ovog istraživanja ogleda se u hibridizaciji oklaska kukuruza i ljuske kikirikija radi postizanja podesivih svojstava u pogledu apsorpcije vlage i mehaničkih karakteristika.

Dobijeni rezultati potvrđuju značajan potencijal kompozita proizvedenih od poljoprivrednog otpada za održive konstrukcije i funkcionalne primene.

Ključne reči: Oklasak kukuruza, ljuska kikirikija, hibrid, kompozit, upijanje vode.

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