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A Study On The Effect Of Corn Cob Nano Particles On The Physico-Mechanical Properties Of Waste Expanded Polystyrene

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Abstract: The effect of the inclusion of Corn Cob Nano-Particles (CCNP) on the Physico-Mechanical Properties of Waste Expanded Polystyrene (WEPS) based composite was studied. Six samples with nomenclature A, B, C, D, E and F were prepared with the composition of WEPS and CCNP in the ratio 100/0g, 95/5g, 90/10g, 85/15 g, 80/20 and 75/25g, respectively. These samples were produced by compounding the composites on a laboratory two-roll mill and the properties of the composites were tested. 98.3% of the corn cob had particle distribution falling between 10 and 100 nm using a nanoparticle size analyzer. The impact strength and hardness of the composite increased as filler loading increased, while tensile strength decreased as filler loading increased. Sample A has an impact strength of 0.088 J/mm while sample F has impact strength of 0.243 J/mm. Sample A has a hardness value of 32.7 while sample F has a hardness value of 59.6 on shore D. Sample A has a tensile strength of 16.116MPa while sample F has a value of 6.091MPa. Sample B gave good water absorption and flammability properties. Conclusively, some mechanical properties of the WEPS have been improved by the reinforcing CCNP. The composite can be used for egg and fruit crates and other forms of packaging.

***Keywords**: Expanded polystyrene, Nanoparticles, Corn Cob, Composite, Mechanical properties.*

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1.0 Introduction

Plastic wastes such as expanded polystyrene are one of the major components of global municipal solid waste and present a promising raw material source for composite production. Hence, the development of new value-added products, to utilize agro and allied wastes and low-cost recycled thermoplastics, is assuming greater importance (Bavan & Kumar, 2010; Zurina *et al*., 2004).

In recent years, there is growing trend in the use of organic fillers in the manufacture of polymer composites due to their low density, low cost and non-abrasiveness (Cletus, 2002; Mengelogbu *et al*., 2000). Corn cob, which is a major agricultural waste, has a huge potential as an organic filler, it is generated as a byproduct of corn cultivation and it comprises of a central core composed of both hard and soft woody material, along with lignin, cellulose, and hemicellulose (Umoren & Utin, 2024). Approximately 0.3 tons of corncobs are generated for every ton of processed corn, estimating the world's annual corncobs production to be around 363 million tons (Felipe *et al*., 2023). Unlike common agricultural residues, corn cob is nutrient-dense and difficult to recycle as fertilizer or feed. Its fiber composition is similar to that of wood, allowing it to act as a wood substitute (Choi *et al*., 2022). Moreover, these natural fillers yield better mechanical strength when added with thermoplastics or thermoset resins. The mechanical properties of particulate-filled polymer composites depend strongly on the particle size, particle-matrix interface adhesion and particle loading (Ishiaku *et al*., 2007).

Expanded Polystyrene (EPS) is a white foam plastic material produced from solid beads of polystyrene. It is a closed-cell, rigid foam material produced from styrene (which forms the cellular structure) and Pentane (which is used as a blowing agent). Both styrene and pentane are hydrocarbon compounds and are obtained from petroleum and natural gas byproducts. (Wypyche *et al*., 2012)

It has a very light weight with density ranging from 11-32Kg/m^3, very low thermal conductivity, low moisture absorption and excellent cushioning properties. Its chemical resistance is nearly equivalent to polystyrene, it is 98% air and it is recyclable. The manufacture of Styrofoam EPS produces no ozone-depleting gases and uses no chlorofluorocarbons (CFCs), which plays a positive role in reducing carbon dioxide emissions and the effects of global warming (Digenis *et al*., 2022).

For several years, EPS has been utilised as a material of choice in several food packaging applications, cost-effective and energy-efficient insulation in construction applications, as well as cushion transport packaging material for shock-sensitive goods etc. (Wunsch 2020). The findings of this study could contribute to sustainable materials development by converting agro-waste and plastic waste into useful composites for packaging and insulation applications

2. 0 Materials and Methods

2.1 Materials

The main materials used in this research include Waste Expanded Polystyrene (WEPS), which was collected from a dumpsite in the Samaru environs, and corn cobs, which were obtained from the Samaru market in Sabon Gari, Zaria, Kaduna State.

2.2 Methods

2.2.1 Material Preparation

The corn cobs were cleaned by washing with distilled water to remove contaminants, sun-dried, ground, and ball-milled for 72 hours. The resulting powder was sieved using a 75 µm sieve. The WEPS was also washed with distilled water and sun-dried.

2.2.2 Nanoparticle Size Analysis

The nanoparticle size was analyzed using a Malvern Zetasizer instrument. The size measurement was carried out using Dynamic Light Scattering (DLS), a technique that determines particle size by measuring Brownian motion and analyzing the intensity fluctuations in the scattered light from a laser beam.

2.2.3 Formulation and Preparation of Composite

The composites were produced by mixing WEPS and corn cob nanoparticles (CCNP) on a two-roll mill (Reliable Rubber Machinery Company) at a compounding temperature of 120 °C. The mixtures were then molded using a hydraulic hot press (Wenzhou Zhiguang Machine Co. Ltd) at 130 °C, following the formulation shown in Table 1.

Table 1: Formulation of WEPS-CCNP Composites

Material	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F
WEPS (g)	100	95	90	85	80	75
CCNP (g)	0	5	10	15	20	25

2.2.4 Tensile Strength Test

Tensile tests were conducted using a Transcell Technology Tensometer (Model: BOB-200, Capacity: 200 kg, Output: 1.9951 mV/V) according to ASTM D638. Dumbbell-shaped samples were subjected to a tensile force, and properties such as tensile strength, percentage elongation, and modulus were recorded.

2.2.5 Impact Strength Test

Impact energy tests were performed using an Izod Impact Tester (Resil Impactor Testing Machine), following ISO 179 and ASTM D256 standards. Specimens were cut to dimensions of 50 × 10 mm with a thickness of 7 mm. The impact energy was measured and the impact strength was calculated accordingly.

2.2.6 Hardness Test

The hardness of each composite was measured using a Vickers Hardness Tester (Model: MV1-PC, Serial No: 07/2012-1329) using the Shore A scale in accordance with ASTM D785-08. The test was repeated three times for each sample, and the average hardness value was recorded.

2.2.7 Water Absorption Test

All samples were immersed in water for five days. The change in weight was recorded after every 24 hours, and the percentage of water absorbed was calculated.

2.2.8 Flammability Test

This test followed a modified ASTM D4804 procedure. A 10 mm mark was made on each sample. The specimen was clamped horizontally with 10 mm of its length (the propagation distance, Dp) protruding. The free end was ignited, and the time to ignition (**It**) was recorded. The time for the flame to reach the 10 mm mark (Pt) was also recorded. The burning rate was calculated using the formula:

$$Rate\ (nm/s)\ = D_p(P_t - I_t) \qquad (1)$$

where D_P = Propagation distance (mm), P_t= Flame propagation time (s), I_t = Ignition time (s).

3.0 Results and Discussion

3.1 Particle Size Analysis versus Other Properties

As shown in the dynamic light scattering plot based on size distribution by intensity (Fig. 1), 98.3% of the corn cob nanoparticles (CCNPs) are within the nanoscale range, with an average size of 76.62 nm. This finding demonstrates a successful milling process and confirms the sample's classification as a nanomaterial. The presence of such a high percentage of fine particles significantly enhances the surface area-to-volume ratio, which is a critical factor in improving the bonding interaction between the filler and the polymer matrix. This characteristic directly influences the composite's mechanical behavior, particularly in terms of hardness and impact resistance, and has an indirect effect on water absorption and flammability. The uniform distribution of nanoparticles enhances load transfer efficiency and stress dispersion, improving the structural integrity of the final composite. Therefore, the observed particle size distribution confirms the suitability of CCNPs for nanocomposite applications that demand enhanced mechanical strength and surface performance.

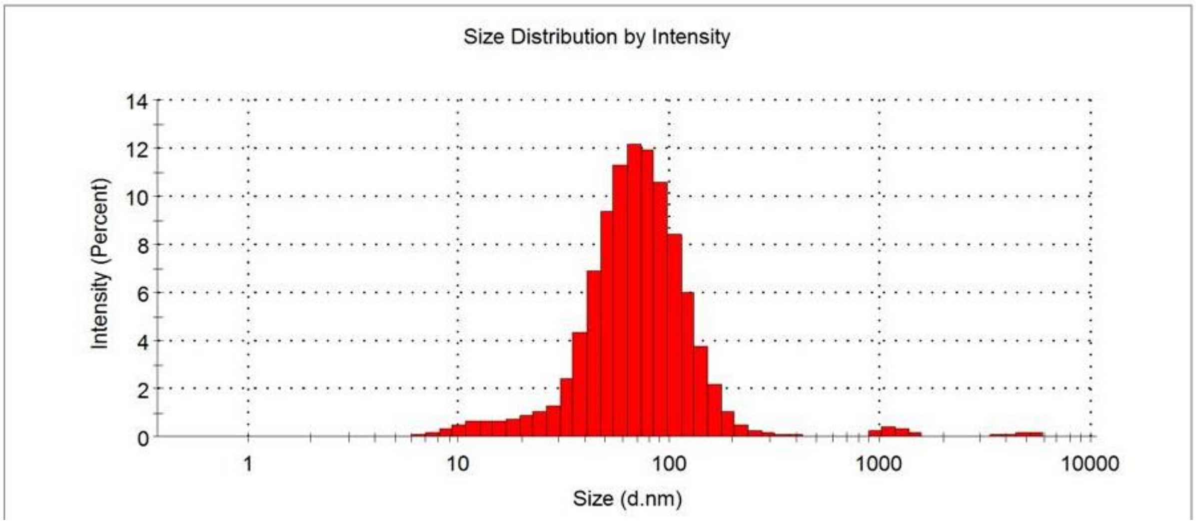

Fig. 1: Nano particle size Analysis

3.2 Tensile Strength versus Impact Strength

A comparison of the tensile and impact strength of the composite materials (Figs. 2 and 3) reveals contrasting trends with increasing CCNP content. The tensile strength consistently decreases as the CCNP loading increases. This suggests that the nanoparticles, despite their reinforcing nature, may act as stress concentrators or introduce weak interfacial zones when not well-dispersed or poorly bonded to the matrix. The resulting discontinuity in the polymer chain network impairs the composite's ability to resist elongation or tensile deformation. In contrast, the impact strength of the composite increases progressively with the addition of CCNPs. The enhanced impact resistance is indicative of improved toughness, where the nanofillers may contribute to mechanisms such as crack deflection, energy dissipation, and plastic deformation, which increase the material's resistance to sudden fracture. This inverse relationship between tensile strength and impact strength underscores a fundamental trade-off: while strength under gradual loading decreases, the material becomes more durable under impact conditions. Consequently, low filler contents are recommended where load-bearing is critical, while higher CCNP concentrations are favorable for impact-sensitive applications.

3.3 Hardness versus Water Absorption

The hardness of the composite increases steadily with the increasing addition of CCNPs (Fig 4). This behavior can be attributed to the stiffening effect of the embedded nanoparticles within the polymer matrix. As rigid reinforcements, CCNPs limit the mobility of the polymer chains and increase resistance to surface indentation or wear. This stiffening effect improves the composite's durability and makes it suitable for use in environments requiring resistance to scratching, abrasion, or compressive force.

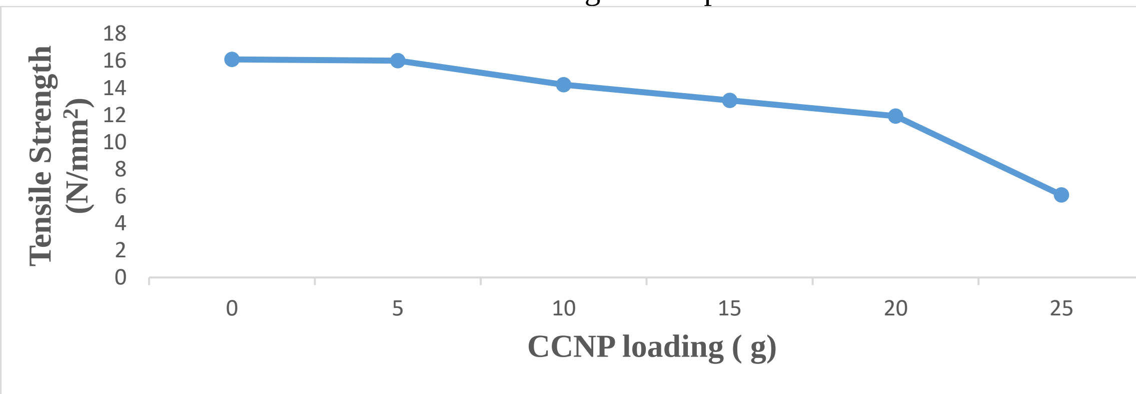

Fig. 2: Effect of CCNP on the tensile strength of the composite

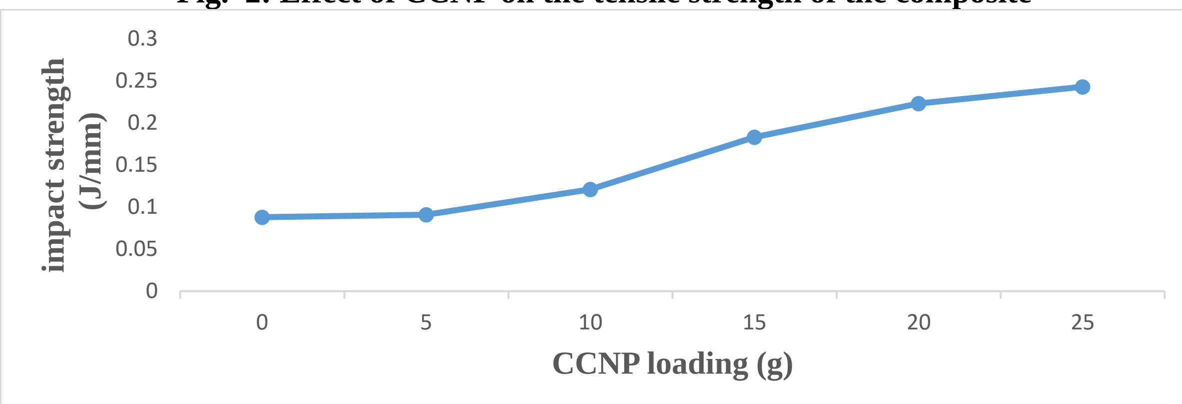

Fig. 3: Effect of CCNP on the impact strength of the composite

Conversely, water absorption of the composite also increases with higher filler loading. The cellulose-based CCNPs are inherently hydrophilic due to the presence of hydroxyl groups on their surface, which attract water molecules. Although the base polymer matrix may be hydrophobic, the incorporation of these bio-based fillers introduces pathways for moisture ingress. While Sample A, composed solely of the polymer matrix, exhibited no water absorption over five days, other samples with CCNPs demonstrated varying degrees of moisture uptake. This implies a loss of water resistance with increasing filler content, which may compromise the composite's dimensional stability and promote degradation in humid or wet environments. Therefore, while increasing CCNP enhances surface hardness, it also introduces vulnerability to moisture, necessitating additional protective treatments in certain applications.

3.5 Water Absorption Test

The percentage of water absorbed by the composite at different filler loading is shown in Fig. 5. The result obtained showed that water absorption by the composite increased with increase in filler loading for the period of 5 days, this could be as a result of the hydrophilic nature of the CCNP. Sample A did not absorb any water for the period of 5days this could be as a result of the hydrophobic nature of the polymer matrix. A similar trend was reported by James (2006). Sample B did not also absorb water for the first two days, but increase in water absorption was later observed for the following three days.

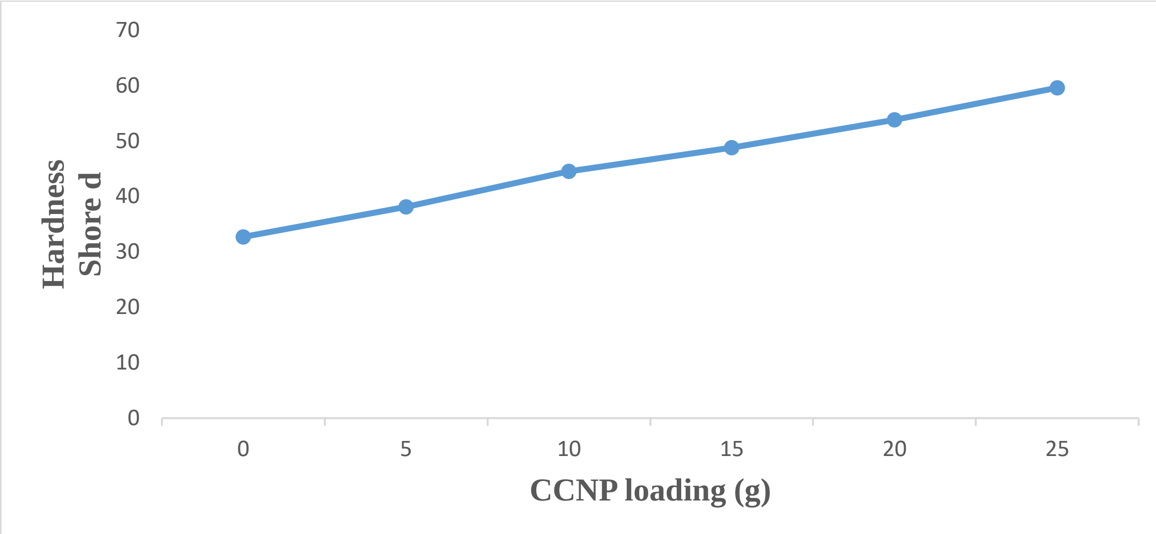

Fig. 4: Effect of CCNP on the hardness of the composite

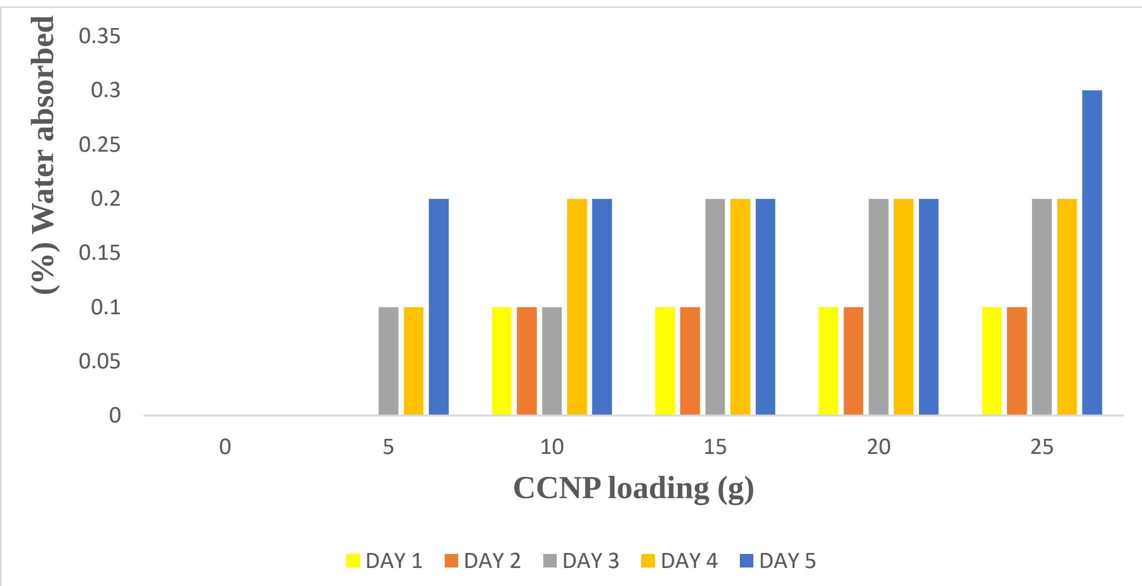

Fig. 5: Effect of CCNP on the Water Absorption of the composite

3.4 Flammability versus Other Properties

The flammability characteristics of the composite materials (Fig. 6) show that all samples are flammable, with increased CCNP loading leading to higher flammability. This result is expected due to the organic and cellulose-rich nature of corn cob, which acts as a combustible component within the matrix. Sample F, which contains the highest amount of CCNP, was observed to ignite more easily and deform rapidly when exposed to heat or open flame. On the other hand, Sample B, with a lower filler concentration, displayed reduced flammability and slower burning behavior. These observations highlight a drawback of using untreated natural fillers in polymer composites, particularly where fire resistance is a critical requirement. Despite the mechanical advantages offered by CCNPs, the increased fire susceptibility at higher loadings limits their use in applications involving exposure to elevated temperatures or open flames. Thus, for the material to be utilized in areas such as electrical casings, construction panels, or interior automotive parts, it is essential to integrate flame-retardant agents or modify the fillers to enhance thermal stability.

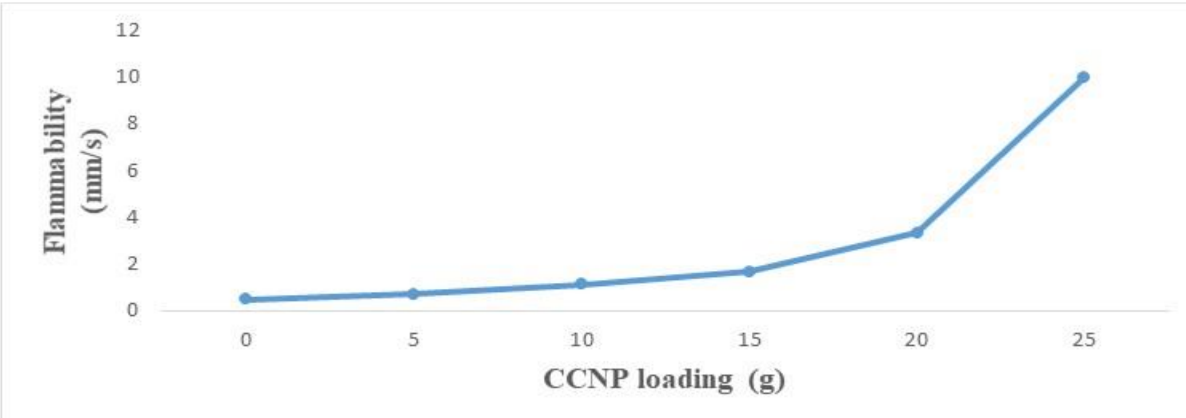

Fig. 6: Effect of CCNP on the Flammability of the Composite

The interplay between the different tested properties illustrates the complex effects of CCNP loading on the performance of polymer composites. While the nanoparticle size analysis confirms the successful preparation of nanomaterials, the mechanical and thermal tests reveal both strengths and weaknesses associated with increasing filler content. Improved impact strength and hardness suggest better wear and shock resistance, making the composite suitable for protective components and structural applications with low tensile stress demands. However, the reduction in tensile strength and increase in water absorption and flammability highlight critical areas requiring further optimization. Surface treatments, compatibilizers, or hybrid filler strategies may be employed to address these limitations and tailor the material for specific use cases.

In summary, the optimized application of corn cob nanoparticle-reinforced composites depends on balancing performance characteristics with the intended environmental and mechanical demands. The findings from this study provide valuable insights into the design of sustainable, bio-based nanocomposites for use in industries such as automotive, packaging, interior architecture, and consumer goods manufacturing of the polymer composite, a summary table has been developed. This table presents the trends observed across key physical and mechanical properties as CCNP loading increases, along with the corresponding significance of each trend and its implication for practical applications. The purpose of this table is to aid in the understanding of performance trade-offs and guide the selection of CCNP-reinforced composites based on specific engineering or environmental requirements.

The summary provided in Table 1 offers a concise view of the overall behavior of the composite material as a function of increasing CCNP content. It is evident that the nanoparticles consistently influence multiple properties, producing both desirable and undesirable outcomes.The particle size analysis confirms that the material retains its nanostructure even after processing. This result is significant because smaller particle sizes contribute to better dispersion and stronger interfacial bonding within the matrix. Such characteristics make the material suitable for reinforcement in high-performance, lightweight structural components, particularly in the automotive and aerospace industries.

Table 1: Summary Table of Trends and Implications

Property	Effect of Increasing CCNP	Significance	Application Implication
Particle Size	Mostly within nanoscale	Better interfacial interaction	Reinforcement in lightweight, high-strength materials
Tensile Strength	Decreases	Lower load-bearing capacity	Best at low filler content for structural applications
Impact Strength	Increases	Improved toughness and energy absorption	Ideal for impact-sensitive parts
Hardness	Increases	Improved scratch/wear resistance	Flooring, dashboards, packaging
Water Absorption	Increases	Reduced environmental resistance	Needs surface modification for wet/humid conditions
Flammability	Increases	Reduced fire safety	Requires flame retardants for thermal applications

Tensile strength, however, shows a decreasing trend with higher filler loading. This decline suggests that although the nanoparticles enhance certain surface properties, they may also introduce micro-defects or reduce chain continuity when excessively added. The implication is that for applications requiring strong tensile resistance—such as load-bearing panels or structural frames—lower CCNP contents should be used to maintain performance.

Conversely, impact strength increases with CCNP concentration, indicating an enhancement in energy dissipation and fracture resistance. This improved toughness makes the composite an excellent candidate for components subjected to shock or dynamic stress, including protective casings, helmets, and automobile interiors.

The increasing trend in hardness is beneficial for applications where surface durability is essential. The enhanced resistance to wear and abrasion means that the material could be deployed in flooring tiles, dashboards, and packaging materials where frequent contact or mechanical stress is expected.

Water absorption also increases with more CCNPs, owing to the hydrophilic nature of cellulose. This behavior poses a challenge for environmental durability, particularly in wet or humid climates. Therefore, further surface modification or the addition of hydrophobic coatings may be necessary when deploying the material in such conditions.

Finally, flammability rises with the addition of CCNPs, a consequence of their organic and combustible nature. This presents a major safety concern for applications involving heat or open flame. For thermal or fire-sensitive environments, it is imperative to incorporate flame retardants or fire-resistant additives to ensure compliance with safety standards. Finally, the trends summarized in Table 1 highlight the dual nature of CCNPs as both performance-enhancing and potentially limiting agents in polymer composites. By understanding and managing these trade-offs, material engineers can design application-specific composites that meet targeted functional requirements while leveraging the sustainability and low cost of corn cob-derived nanofillers.

4.0 Conclusion

The study investigated the influence of corn cob nanoparticles (CCNPs) on the mechanical, physical, and thermal properties of polymer composites. The findings revealed that the particle size distribution of the ball-milled CCNPs was predominantly within the nanoscale range, with over 98% of particles having diameters around 76.62 nm. This confirms the successful production of nanostructured fillers suitable for enhanced composite performance. The tensile strength of the composites was observed to decrease with increasing CCNP content, likely due to interference with the matrix's intermolecular bonding. In contrast, the impact strength and hardness of the composites increased with higher CCNP loading, suggesting that the addition of nanoparticles improved the material's toughness and resistance to deformation or abrasion.

The water absorption capacity of the composites also increased with CCNP content, attributable to the hydrophilic nature of the corn cob-derived filler. This property indicates a potential vulnerability of the material to moisture-induced degradation, which may limit its application in humid or water-rich environments unless additional treatment is applied. Similarly, the flammability of the composites increased with CCNP addition, pointing to reduced fire safety and underscoring the need for flame retardants when these materials are to be used in high-temperature or fire-prone settings.

In conclusion, corn cob nanoparticles serve as an effective reinforcing filler for enhancing certain properties of polymer composites, particularly impact strength and hardness, while introducing some drawbacks such as reduced tensile strength, increased water absorption, and higher flammability. Therefore, for applications requiring high impact resistance and surface durability, such as automotive interiors or packaging materials, these composites are highly suitable. However, in applications requiring high tensile strength, environmental resistance, or fire safety, the use of CCNP-reinforced composites should be limited or accompanied by appropriate modifications.

It is recommended that further work be carried out to improve the water and fire resistance of the composites, possibly through chemical surface treatments, the incorporation of hydrophobic or fire-retardant additives, or the use of compatible matrix materials. Optimization of CCNP loading levels should also be explored to achieve a balance between mechanical performance and environmental stability. Moreover, lifecycle assessment and cost-performance analyses should be conducted to establish the broader industrial viability and environmental sustainability of CCNP-based composites.

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Declaration

Consent for publication

Not applicable

Availability of data

Data shall be made available on demand.

Competing interests

The authors declared no conflict of interest

Ethical Consideration

Not applicable

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Authors' Contribution

Mosunmade Aiyejagbara, Kevin Ejiogu and Uche Ibeneme carried out the new particle and mechanical analyses of this research work. Tachye N.B Shekarri, Eli Musa, Bisike Chidebere and Chielo Okeke carried out the physical properties of the work. Chielo Okeke and Tachye N.B Shekarri contributed to the writing of the research work. All authors read the final corrected work.