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Comparative Evaluation of Mechanical, Structural, and Morphological Properties of Corncob Ash and Graphite-Filled Epoxy Composites

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Abstract

This study presents a comparative investigation of the mechanical, structural, and morphological properties of epoxy composites reinforced with corncob ash (CCA) and graphite fillers at varying weight percentages (0–25 wt%). Composite specimens were fabricated using the hand lay-up technique and characterised through tensile, flexural, impact, and hardness tests, complemented by X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy-dispersive X-ray (EDX) analyses. The results revealed that corncob ash epoxy composites exhibited a maximum tensile strength of 14.34 MPa at 25 wt% filler loading, while graphite epoxy composites achieved the highest tensile strength of 13.24 MPa at 5 wt% loading. The highest Vickers hardness values were 25 HV and 22.37 HV for CCA and graphite composites at 25 wt%, respectively. Graphite composites demonstrated superior impact strength (5.44 J at 25 wt%), while CCA composites showed comparable performance (5.17 J at 0 wt% control). Flexural strength peaked at 15 wt% for both fillers, with graphite composites reaching 38.77 MPa and CCA composites achieving 32.24 MPa. XRD analysis confirmed crystalline phases in both composite systems, and SEM/EDX characterisation revealed the dispersion behaviour and elemental composition of the fillers within the epoxy matrix. The findings suggest that corncob ash, an agricultural waste material, is a viable and sustainable alternative to conventional graphite filler in epoxy composite applications, offering comparable mechanical performance with significant environmental and economic advantages.

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Keywords: *Corncob ash; graphite; epoxy composite; mechanical properties; XRD; SEM; EDX; sustainable materials; agricultural waste*

1. INTRODUCTION

The growing demand for lightweight, cost-effective, and environmentally sustainable engineering materials has driven significant research interest in polymer matrix composites reinforced with natural and waste-derived fillers (Kumar et al., 2025; Arpitha et al., 2024). Epoxy resins, widely used as matrix materials in structural composites due to their excellent adhesion, chemical resistance, and mechanical properties, have been extensively studied in combination with both synthetic and natural reinforcements (Fouly et al., 2021; Patsidis & Souliotis, 2023).

Graphite, a well-established carbonaceous filler, has been utilised in epoxy composites to enhance mechanical, thermal, and tribological properties. Studies have demonstrated that graphite incorporation improves the Young's modulus, compressive strength, and wear resistance of epoxy-based systems, though the extent of improvement depends on filler loading, particle size, and dispersion quality (Shelar & Suryawanshi, 2024; Nagesh et al., 2026). However, graphite is a finite mineral resource with associated extraction and processing costs, motivating the search for sustainable alternatives.

Agricultural waste materials represent a promising class of alternative fillers due to their abundance, low cost, and environmental benefits. Corncob, one of the most prevalent agricultural residues globally, has attracted attention as a potential reinforcement material in polymer composites. When converted to ash through thermal processing, corncob yields a silica-rich particulate material that can be incorporated into polymer matrices (Fouly et al., 2021; Arpitha et al., 2024). Previous studies have shown that corncob-derived fillers can improve the compressive strength, hardness, and tribological properties of epoxy composites at appropriate loading levels (Mestry et al., 2022).

Despite these advances, there remains a limited body of comparative research directly evaluating corncob ash against conventional fillers such as graphite in the same epoxy matrix system under identical processing and testing conditions. Such comparative data are essential for establishing the viability of agricultural waste fillers as replacements for mineral-based reinforcements. Furthermore, comprehensive characterisation combining mechanical testing with structural (XRD) and morphological (SEM/EDX) analyses is needed to understand the reinforcement mechanisms and failure behaviour of these composites.

This study addresses this gap by fabricating and characterising epoxy composites reinforced with corncob ash and graphite fillers at weight percentages ranging from 0 to 25 wt%. The mechanical properties evaluated include tensile strength, tensile modulus, flexural strength, flexural modulus, flexural strain, impact strength, and Vickers hardness. Structural characterisation was performed using XRD, while SEM and EDX analyses were employed to examine the morphology and elemental composition of the composites. The objective is to provide a comprehensive comparative assessment of the two filler systems and evaluate the potential of corncob ash as a sustainable alternative to graphite in epoxy composite applications.

2. METHODS

2.1 Materials

The matrix material used was a two-part epoxy resin system consisting of a bisphenol-A-based epoxy resin and an amine-based hardener, mixed in the manufacturer’s recommended ratio. Two filler materials were employed: (i) graphite powder, a commercially sourced carbonaceous mineral filler, and (ii) corncob ash (CCA), prepared by controlled combustion of dried corncob waste obtained from local agricultural sources. The corncob residue was air-dried, combusted in a muffle furnace, and the resulting ash was ground and sieved to obtain a fine particulate suitable for composite fabrication.

2.2 Composite Fabrication

Composite specimens were fabricated using the hand lay-up technique. Each filler was incorporated into the epoxy matrix at weight percentages of 0 (control), 5, 10, 15, 20, and 25 wt%. The filler was gradually added to the resin under continuous mechanical stirring to ensure uniform dispersion. The hardener was subsequently added, and the mixture was poured into steel moulds, degassed, and allowed to cure at room temperature for 24 hours. Post-curing was carried out at elevated temperature to ensure complete cross-linking of the epoxy network.

2.3 Mechanical Testing

Tensile tests were conducted in accordance with ASTM D638 using a universal testing machine at a crosshead speed of 2 mm/min. Flexural strength was determined via three-point bending tests following ASTM D790. Impact resistance was evaluated using the Charpy impact test method (ASTM D6110). Vickers hardness measurements were taken at multiple locations on each specimen surface, and the average values were recorded. A minimum of three specimens per composition were tested to ensure reproducibility.

2.4 Structural and Morphological Characterisation

X-ray diffraction (XRD) analysis was performed to identify the crystalline phases and structural characteristics of the composite materials. Scanning electron microscopy (SEM) was employed to examine the fracture surfaces and filler dispersion within the epoxy matrix. Energy-dispersive X-ray spectroscopy (EDX) was conducted to determine the elemental composition of the composites at selected filler loadings.

3. RESULTS AND DISCUSSION

3.1 Tensile Strength

The tensile strength results for both graphite-filled and corncob ash-filled epoxy composites are presented in Figure 1. For graphite epoxy composites, a progressive decrease in tensile strength was observed with increasing filler loading from 5 wt% to 25 wt%. The highest tensile strength of 13.24 MPa was recorded at 5 wt% graphite loading, while the lowest value of 0.48 MPa was observed at 25 wt%. This decline is consistent with findings reported by Shelar and Suryawanshi (2024), who attributed strength reduction at higher filler loadings to particle agglomeration and poor interfacial adhesion between the filler and the matrix.

In contrast, the corncob ash epoxy composites exhibited a different trend. An initial decrease in tensile strength was observed at 5 wt% CCA loading, followed by a progressive increase from 10 wt% to 25 wt%, with the maximum tensile strength of 14.34 MPa achieved at 25 wt% loading. This behaviour suggests that at lower concentrations, the CCA particles may not have been uniformly dispersed, leading to stress concentration points. However, at higher loadings, improved particle packing and enhanced filler–matrix interaction contributed to the strength increase. Similar trends have been reported for other agricultural waste fillers in epoxy systems (Nagaraja et al., 2024; Fouly et al., 2021).

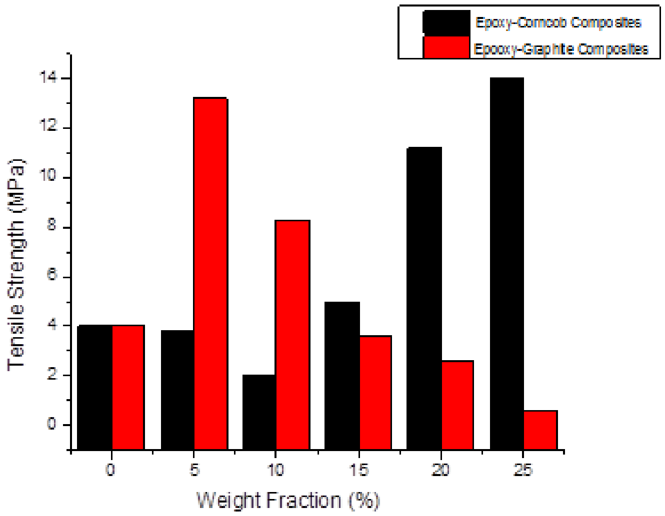


Figure 1. Tensile Strength of Epoxy Composites

3.2 Impact Strength

The Charpy impact test results revealed distinct behaviours for the two filler systems. Graphite epoxy composites demonstrated a consistent enhancement in impact toughness with increasing filler content, reaching a maximum impact strength of 5.44 J at 25 wt% loading. This improvement can be attributed to the ability of graphite particles to absorb and dissipate impact energy through crack deflection and crack pinning mechanisms (Nagesh et al., 2026). For the corncob ash epoxy composites, the impact strength showed non-linear behaviour. The control specimen (0 wt%) exhibited an increase from 4.31 J to 5.17 J, but the addition of 5 wt% CCA resulted in a decrease to 4.04 J. Subsequently, the impact strength recovered and increased progressively from 15 wt% to 25 wt% loading. The initial reduction at 5 wt% may be attributed to poor filler–matrix adhesion at this specific loading level, where the filler particles act as defect sites rather than energy-absorbing reinforcements. This phenomenon has been documented in other particulate-filled polymer composites, where optimal filler–matrix adhesion occurs only at specific loading thresholds (Arpitha et al., 2024; Kumar et al., 2025).

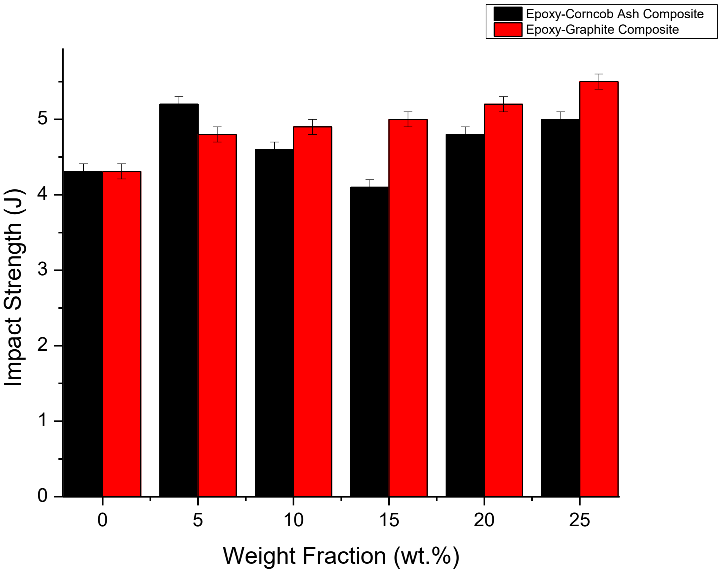


Figure 2. Impact Strength of Epoxy Composites

3.3 Hardness

Vickers hardness measurements showed progressive improvements with increasing filler content for both composite systems. The graphite epoxy composite achieved its highest Vickers hardness number (VHN) of 22.37 HV at 25 wt% graphite loading, demonstrating a positive correlation between filler content and surface hardness. This is consistent with the general principle that the incorporation of hard particulate fillers increases the resistance of polymer composites to localised plastic deformation (Patsidis & Souliotis, 2023). The corncob ash epoxy composites exhibited a slightly superior hardness response, with the highest VHN of 35.3 HV recorded at 25 wt% CCA loading. An interesting observation was the temporary hardness decrease at 5 wt% loading after an initial increase from 0 to 5 wt%, followed by a sustained increase from 10 to 25 wt%. The higher hardness values achieved by CCA composites compared to graphite composites may be attributed to the silica content present in corncob ash, which is known to enhance the hardness of polymer matrices (Rizal et al., 2020; Fouly et al., 2021).

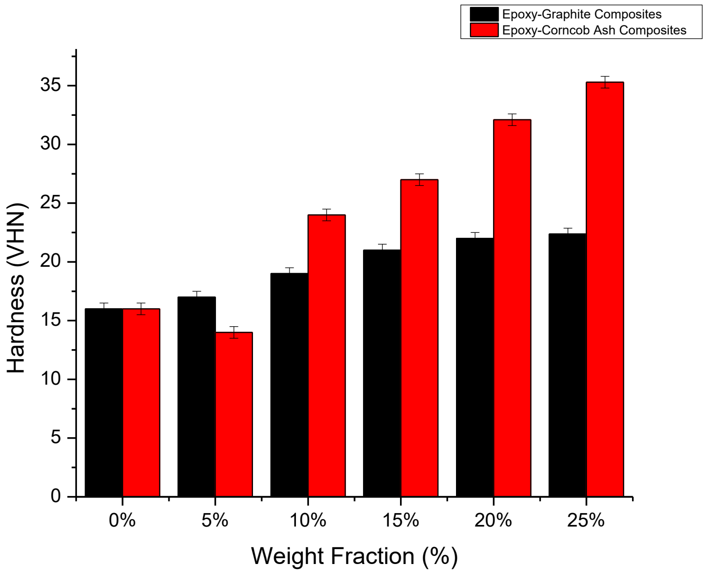


Figure 3. Hardness of Epoxy Composites

3.4 Flexural Strength

The flexural strength of both composite systems showed non-monotonic behaviour with increasing filler content. For graphite epoxy composites, flexural strength increased progressively from 5 wt% to 15 wt%, reaching a maximum of 38.77 MPa at 15 wt% loading. Beyond this optimum, flexural strength decreased at 20 wt% loading. This behaviour is characteristic of particulate-filled polymer composites, where moderate filler loadings enhance load transfer and resistance to bending, while excessive filler content leads to agglomeration and reduced matrix–filler adhesion (Mestry et al., 2022). Similarly, the corncob ash epoxy composites achieved their highest flexural strength of 32.24 MPa at 15 wt% loading, with a rapid increase observed between 15 and 20 wt%, followed by a decline from 20 to 25 wt%. The reduction in flexural strength at higher loadings may be attributed to the formation of agglomerated particles within the epoxy matrix, which create stress concentration sites and weaken the composite's resistance to bending loads. These findings are consistent with those of Nagaraja et al. (2024), who reported similar optimum filler loadings for flexural performance in natural filler-reinforced epoxy systems.

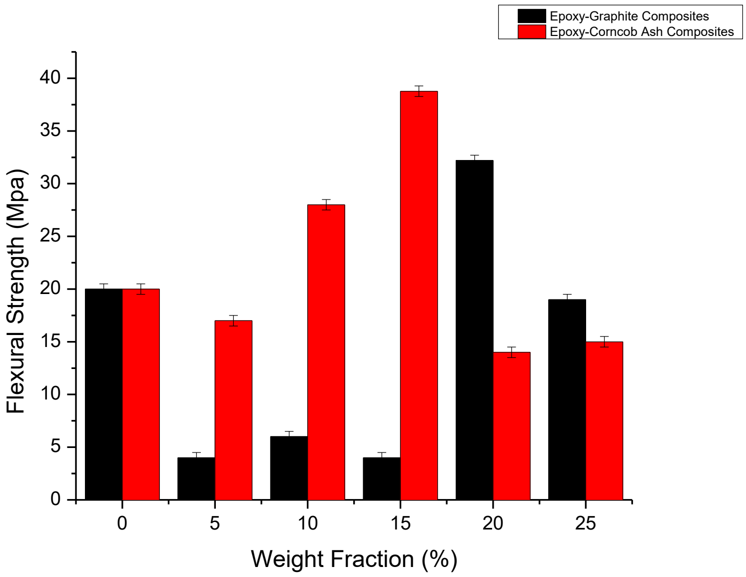


Figure 4. Flexural Strength of Epoxy Composites

3.7 X-Ray Diffraction (XRD) Analysis

Figure 5, 6, and 7 shows the XRD of the materials used, epoxy, corncob ash, and graphite. For the epoxy sample, the XRD pattern (Figure 5) exhibits a broad, diffuse peak centered around 20°–30° 2θ, characteristic of an amorphous structure. This broad diffraction halo is typical of polymeric materials, indicating a lack of long-range crystalline order. The absence of sharp diffraction peaks further confirms the amorphous nature of the epoxy, a property associated with the thermosetting polymer after curing. In the case of corncob ash (Figure 6), the XRD pattern reveals a combination of crystalline and amorphous phases. Sharp peaks at approximately 20° and 26° 2θ are attributed to crystalline silica, specifically quartz, a common mineral phase found in ashes. Additionally, the broad hump observed in the low-angle region (10°–30° 2θ) suggests the presence of amorphous silica, indicating partial vitrification of the corncob during combustion. The mixture of crystalline and amorphous phases points to the ash's potential as a pozzolanic material, with reactive amorphous silica alongside less reactive crystalline silica. The XRD pattern of graphite (Figure 7) shows a dominant, sharp peak around 26° 2θ, corresponding to the (002) plane of graphite. This intense and narrow peak indicates a highly crystalline, well-ordered structure, characteristic of graphite's hexagonal layered arrangement. Smaller peaks at higher 2θ values, around 54.6° 2θ, further confirm the crystalline nature of graphite, showing its layered carbon structure.

These XRD analyses reveal the distinct structural characteristics of each material: epoxy is amorphous, corncob ash contains both crystalline and amorphous components, and graphite is highly crystalline. These structural differences helps into understanding how each material will behave in the composite systems, with epoxy acting as an amorphous matrix, corncob ash serving as a mixed-phase filler, and graphite contributing a crystalline, layered carbon structure to enhance material properties.

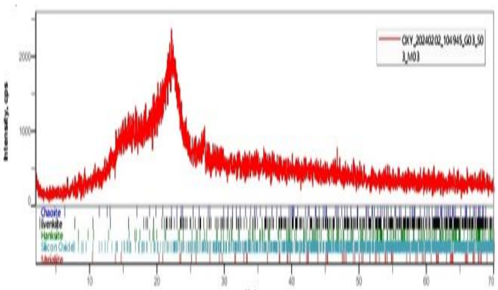


Figure 5. XRD of Epoxy

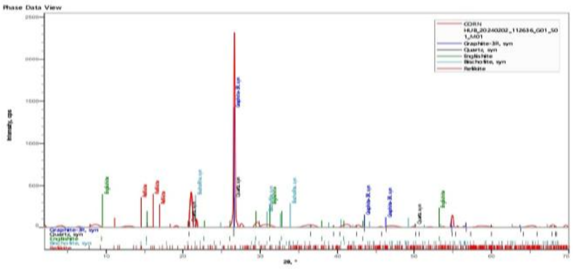


Figure 6. XRD of Corncob Ash

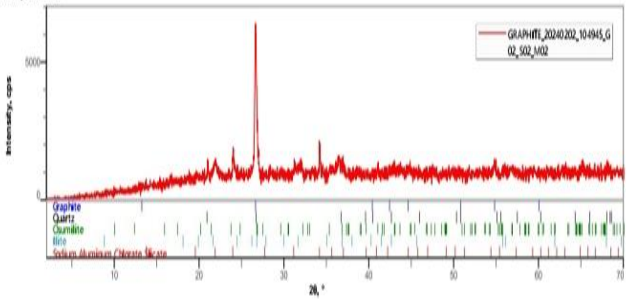


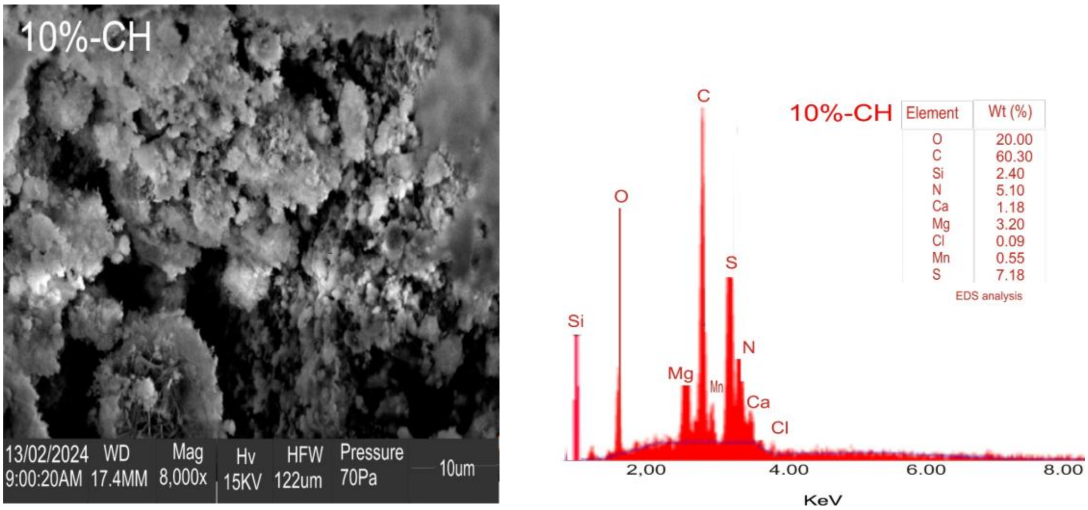
Figure 7. XRD of Graphite

3.8 Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy Analysis.

SEM analysis was performed on the fracture surfaces of each of the 10 wt% epoxy composites. The SEM micrograph of the 10wt.% CCA reinforced epoxy composite revealed the presence of foreign particle inclusions within the matrix, which may have contributed to the reduced tensile strength observed at 10 wt% CCA loading. These inclusions likely acted as stress concentrators, initiating premature failure under tensile loading. Such contamination effects have been reported in other agricultural waste-reinforced composites, where processing conditions significantly influence filler purity and distribution (Magiera et al., 2025; Nagaraja et al., 2024). The SEM analysis of the graphite epoxy composite at 10wt% loading showed relatively better filler dispersion compared to the CCA composite at the same loading. However, both composites exhibited evidence of filler–matrix debonding at certain locations, which is a common failure mechanism in particulate-reinforced polymer composites (Kumar et al., 2025).

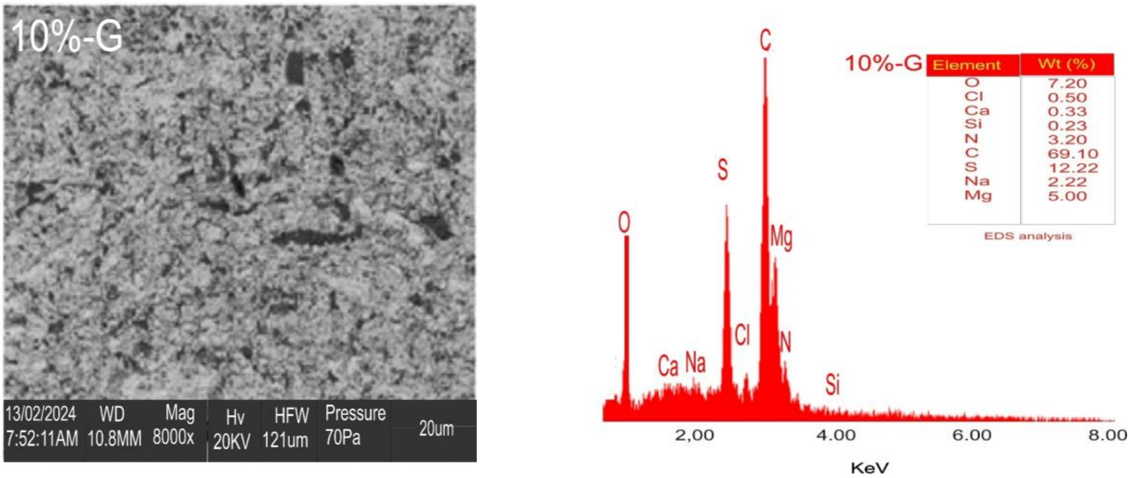
EDX analysis was conducted on 10 wt% specimens of both composite types to determine their elemental composition. The corncob ash epoxy composite was found to consist of 60.30% carbon (C), 20.00% oxygen (O), and 2.14% silicon (Si), among other elements.

The high carbon content reflects both the epoxy matrix contribution and the carbonaceous nature of the corncob ash filler. The presence of silicon confirms the siliceous character of corncob ash, which contributes to its reinforcing effect in the polymer matrix (Rizal et al., 2020). The graphite epoxy composite exhibited a higher carbon content of 69.10%, consistent with the inherently carbon-rich nature of graphite filler. The oxygen content was lower at 7.20%, and silicon was present at 2.14%. The higher carbon-to-oxygen ratio in the graphite composite compared to the CCA composite reflects the more oxidised nature of the corncob ash, which undergoes partial combustion during ash preparation. These compositional differences have implications for the interfacial chemistry between the filler and the epoxy matrix, influencing the overall mechanical performance of the composites.



Element	Wt (%)
O	20.00
C	60.30
Si	2.40
N	5.10
Ca	1.18
Mg	3.20
Cl	0.09
Mn	0.55
S	7.18

Figure 8: Microstructure of 10wt.% Epoxy-CCA Composite



Element	Wt (%)
O	7.20
Cl	0.50
Ca	0.33
Si	0.23
N	3.20
C	69.10
S	12.22
Na	2.22
Mg	5.00

Figure 9**:** Microstructure of 10wt.% Epoxy-Gr Composite

CONCLUSION

This study has provided a comprehensive comparative evaluation of the mechanical, structural, and morphological properties of epoxy composites reinforced with corncob ash and graphite fillers. The results demonstrate that corncob ash is a viable and sustainable alternative to graphite as a filler material in epoxy composites, offering comparable or superior performance in several mechanical properties. The utilisation of corncob ash in polymer composites addresses dual challenges of agricultural waste management and the need for cost-effective, eco-friendly engineering materials. Future work should focus on surface treatment of CCA particles to improve filler–matrix adhesion, investigation of thermal and tribological properties, and long-term durability assessment of CCA-reinforced composites under environmental ageing conditions.

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