Ethiopian Journal of Environmental Studies & Management 19(Suppl.): 883 – 895, 2026
ISSN:1998-0507 doi: https://ejesm.org/doi/v19iSuppl.6
Submitted: September 29, 2026 Accepted: November 11, 2026

MORPHOLOGICAL CHARACTERISTICS OF WOOD–PLASTIC COMPOSITES PRODUCED FROM RESIDUES OF *Gmelina arborea* Roxb.ex Sm., AND *Ceiba pentandra* (L.) Gaertn.

***ORIIRE, L.T.[1] AND OGUNSANWO, O.Y.[2]**
[1]Department of Forest Products Development and Utilization, Forestry Research Institute of Nigeria, PMB 5054, Jericho Hill Estate, Ibadan, Nigeria.
[2] Department of Forest production and Products, University of Ibadan, Oyo State, Nigeria.
*Corresponding author: luke_goodluck@yahoo.com

Abstract
Morphology of wood-plastic composites (WPCs) plays a critical role in determining their physical, mechanical, and durability performance. This study investigated the microstructural characteristics of WPCs manufactured from residues of Gmelina arborea and Ceiba pentandra bonded with recycled low-density polyethylene (LDPE). Composite boards were produced at three wood-to-plastic ratios (1:1, 2:1, and 3:1) and three nominal densities (800, 900, and 1000 kg m⁻³). Scanning Electron Microscopy (SEM) was employed to examine fibre dispersion, matrix continuity, interfacial adhesion, and the occurrence of structural defects within the composites. The micrographs revealed significant differences in fibre–matrix interactions among production variables. Composites produced at higher densities exhibited more compact structures, improved fibre encapsulation, and reduced void formation. Gmelina arborea-based composites showed better interfacial bonding and more homogeneous fibre distribution than those reinforced with Ceiba pentandra. Increased wood loading resulted in fibre agglomeration and microvoid formation due to insufficient polymer coverage. The findings demonstrate that optimization of composite microstructure is fundamental to enhancing the performance of wood-plastic composites manufactured from tropical wood residues.

Keywords: *Wood-plastic, Composite, Morphology Tropical hardwoods*

Introduction

The growing utilization of wood-plastic composites (WPCs) in structural and non-structural applications has stimulated considerable interest in understanding the factors that govern their performance and durability. While the physical and mechanical properties of WPCs are influenced by the characteristics of the constituent materials, the effectiveness of stress transfer within the composite is largely dependent on the quality of interaction between the lignocellulosic reinforcement and the polymer matrix. Consequently, the microstructural arrangement of composite components has become a critical area of investigation in wood composite science (Clemons, 2002; Stark and Rowlands, 2003).

This work is licensed to the publisher under the Creative Commons Attributions License 4.0

At the microscopic level, features such as fibre dispersion, matrix continuity, interfacial adhesion, and void distribution significantly influence the performance of WPCs. A homogeneous dispersion of wood particles within the polymer matrix promotes efficient load transfer and enhances mechanical properties, whereas poor dispersion often results in stress concentration sites that accelerate crack initiation and propagation (Adhikary *et al*., 2008). Similarly, the presence of voids, microcracks, and fibre agglomerations can adversely affect dimensional stability, moisture resistance, and long-term durability of composite materials (Migneault *et al*., 2009).

One of the major challenges associated with WPC production is the inherent incompatibility between wood fibres and thermoplastic polymers. Wood is predominantly hydrophilic because of the abundance of hydroxyl groups present in cellulose, hemicelluloses, and lignin, whereas thermoplastics such as polyethylene exhibit hydrophobic characteristics. This difference in polarity limits interfacial bonding and often results in weak adhesion between the two phases. Poor interfacial interaction may lead to fibre pull-out, inadequate stress transfer, and reduced mechanical performance of the composite (Klyosov, 2007; Lu *et al*., 2000). Therefore, the degree of polymer encapsulation around wood particles is widely recognised as an important indicator of composite quality and durability.

Morphological characterization provides valuable information regarding the internal structure of WPCs and serves as an important tool for interpreting composite behaviour. Among the available techniques, Scanning Electron Microscopy (SEM) has proven particularly effective for examining fibre-matrix interactions and assessing the quality of interfacial bonding. SEM analysis enables direct observation of microstructural features such as fibre pull-out, matrix cracking, void formation, and polymer penetration into wood cell lumens. These observations often provide explanations for variations in mechanical strength, water absorption, dimensional stability, and resistance to biological deterioration reported in composite materials (Fabiyi and McDonald, 2014; Ayrilmis *et al*., 2011).

Furthermore, wood species characteristics can substantially influence composite morphology. Variations in fibre dimensions, cell wall structure, density, and chemical composition affect the interaction between wood particles and polymer matrices during processing. Consequently, composites produced from different wood species may exhibit distinct microstructural features and performance characteristics. Understanding these species-related effects is essential for optimizing raw material selection and improving the engineering properties of WPCs derived from lignocellulosic residues (Oriire *et al.*, 2024).

In this study, the morphological characteristics of wood-plastic composites manufactured from residues of Gmelina arborea and Ceiba pentandra were evaluated using Scanning Electron Microscopy. The investigation focused on assessing fibre dispersion, interfacial adhesion, matrix continuity, and defect formation under different manufacturing conditions. The observed microstructural features were further related to the physical and mechanical behaviour of the composites, providing insights into the

influence of wood species and processing variables on composite performance.

Material and Methods

Preparation of Materials

Plastic waste from sachets water (LDPE) was used as binder in this research, these plastic wastes were collected from factory waste sites at FRIN Consult Ibadan and thoroughly washed before mill. The plastic wastes were dried and mill into particles using hammer milling machine available at waste recycling factory, Wood Reconstituted Section, Forest Products Development and Utilization, FRIN, Ibadan Oyo State Nigeria.

Production of Wood Plastic Composite (WPCs) boards

Sawdust and milled plastic particles were sieved thoroughly with wire mesh of size 250µm, the sawdust was air dried to reduce its moisture content, the required proportion of wood and plastic was hand – mixed thoroughly before feeding into screw extruder machine, the machine consists of feeding hopper, coolant chamber, heater and die. The mixture was heated at the temperature range of 165 – 185^{0}C to produce WPC strands of each combination of plastic/wood ratios was conditioned by cooling in water bath before being pelletized. WPCs pellets were oven – dried at temperature of 65^{0}C for 24hours before feeding into a mould of 360 mm x 360 mm x 10 mm. The mould tray was placed in a hot- press at temperature range of 165 – 190 ^{0}C and press for the period of 45 minutes. After this, the boards were stripped out of the mould and cut into test specimens for the determination of mechanical properties in accordance with ASTM 570 – 98 and ASTM D 790 – 84a.

Board Density Determination

The oven – dry density of the board was determined using specimen dimension 76.2 mm x 25.4 x 6.4 mm. The specimens were oven – dry at 65^{0}C for 48 hours. After cooling in a desiccator, the oven – dry weight (to the nearest 0.01g) and the length, width and thickness (to the nearest 0.01mm) of each specimen was measured. The density of each specimen was computed from the equation (3.3) in accordance with ASTMD 792.

$$Þ\left(\frac{g}{mm3}\right)\frac{M}{V} \quad \text{.....equation (1)}$$

Where, Þ = Density in (g/mm^3), M = Mass in (g), V = Volume in (mm^3)

Mechanical Properties Test

The flexural strength properties were carried out in accordance with ASTM D790: 2002 with sample using universal testing machines (UTM), model WDW 5000 with a load of 50KN and span of 100 mm for a three-point bending flexural tests. Each specimen was supported with two rollers at each end and force exerted at the centre. At the point of failure, the force exerted on the specimen was recorded to determine the strength and modulus of each specimen before and after termite attack. The mechanical properties tested are modulus of rupture (MOR), modulus of elasticity (MOE) the sample was cut into 12mm x 50mm x175mm dimension.

Modulus of Rupture (MOR)

Board samples were cut into 12mm x 50mm x 175mm dimension were carried out in accordance with ASTM D790: 2002. The load was applied on the centre of each board sample until failure of the test sample occurred. The load at which each board failed was recorded. The MOR of the test board samples were calculating using the formula,

$$MOR = \frac{3PL}{2bd2} \quad \text{.....equation (2)}$$

Where MOR= Modulus of rupture ($4/mm^2$), P = the ultimate failure load (N), L = the board span between the machine supports (mm), b= Width of the board sample (mm), d= Thickness of the board sample (mm).

Modulus of Elasticity (MOE)

The modulus of elasticity was calculated from the values obtained from the load – deflection graph during the test for MOR.

The following equation was used

$$MOE = {}^{PL3}/_{4bd3h} \text{.....equation (3)}$$

Where MOE = Modulus of elasticity (N/mm^2), P = Load (N), L = the board span between the machine supports (mm), b= Width of the board sample (mm), d= Thickness of the board sample (mm), h = slope from the graph

Morphological Properties Test

Scanning Electron Microscope (SEM) imaging and sample preparation was done as follows, the selected experimental samples were duly prepared and analyzed in order to detect any structural arrangement in the production variable of the wood plastic composite produced. The etched blocks were mounted on aluminium stubs with carbon tape and gold coated in a Quorum Q150 RES sputter coater. These blocks were viewed in a Zeiss EVO LS15 scanning electron microscope at about 15KV-20KV the fractured surfaces of the flexural test specimens were characterized using Electron Microscopy (EOL JSM-6390LV) at magnifications of 10,000X. SEM images were taken and analyze,

Data Analysis

All statistical analysis in both parts were conducted as a factorial experiment in completely randomized design by means of one-way analysis of variance to determine significance of the main and interacting effects that could emerge. Separations of treatment mean was carried out by using Duncan's Multiple Range Test (DMRT) and this was done to determine the differences between the means and to choose the best treatment combination from the factors considered.

Results and Discussion

Figures 1–3 illustrate the influence of wood species, wood–plastic ratio, and target density on the mechanical properties of the wood–plastic composites (WPCs). The results show that these production variables significantly affected the modulus of elasticity (MOE), modulus of rupture (MOR), and density of the composites. Composites produced from *Gmelina arborea* generally exhibited superior strength properties, while those from *Ceiba pentandra* demonstrated comparatively higher stiffness under selected formulations. Increasing wood content increased composite density; however, excessive wood loading did not consistently improve mechanical performance due to weaker interfacial bonding between the wood particles and polymer matrix.

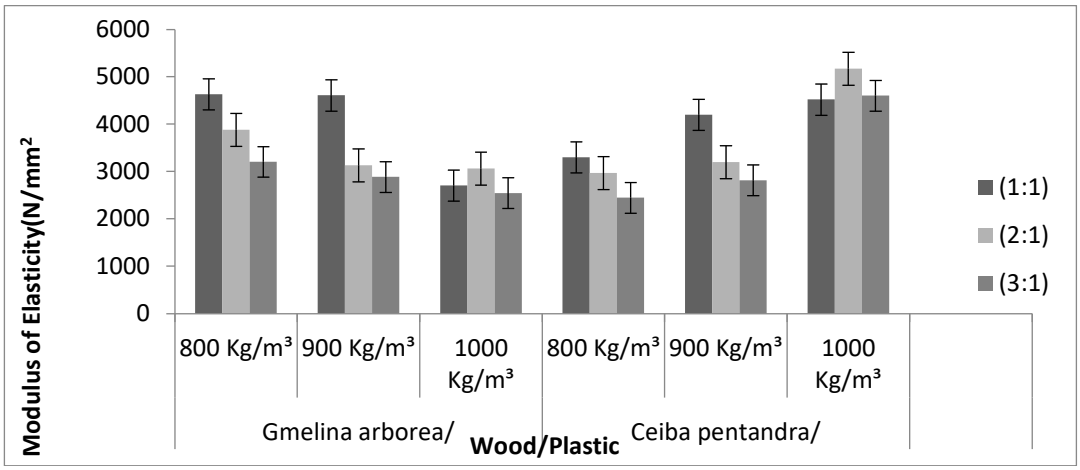


Fig. 1: Effect of production variables on modulus of elasticity of wood plastic composites

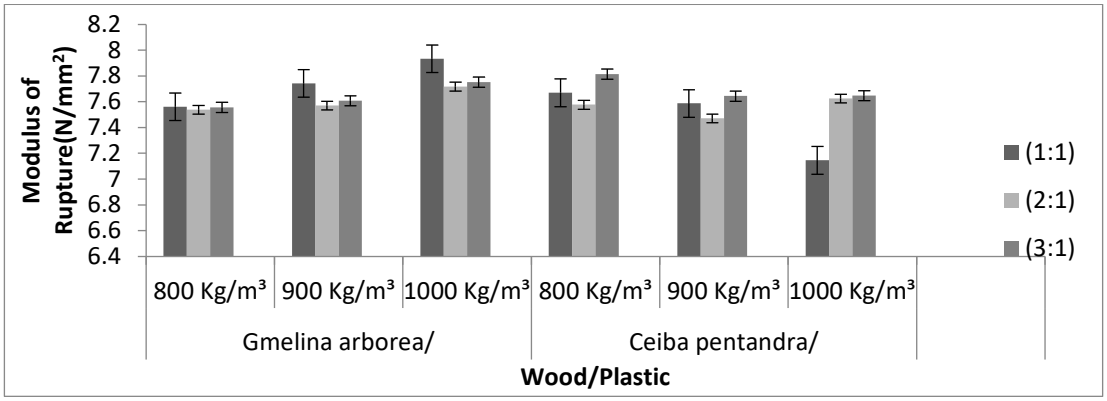


Fig. 2: Effect of production variables on modulus of rupture of wood plastic composites

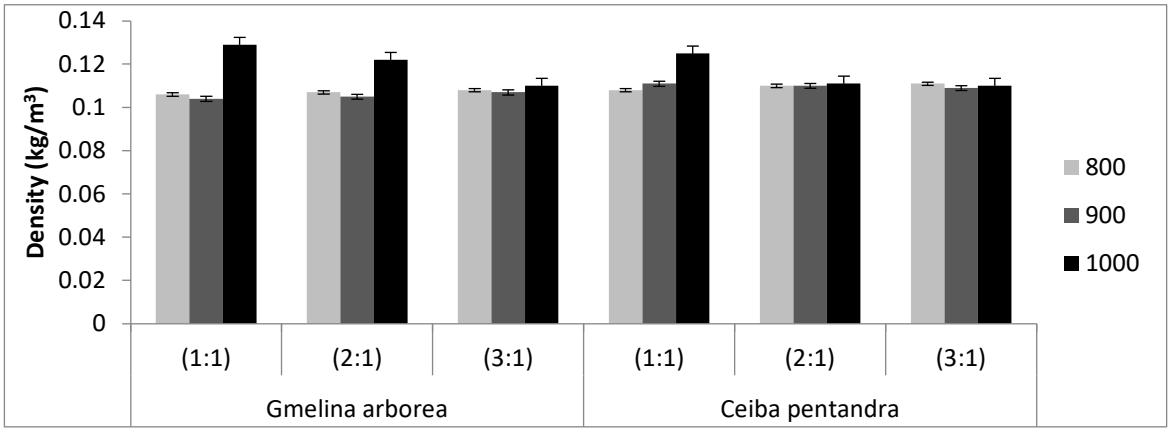


Fig. 3: Effect of production variables on density observed for wood plastic composites

SEM Analysis at 800 kg m⁻³

The SEM micrographs presented in Plates 1a–f reveal the influence of fibre loading and wood species on the microstructural characteristics of WPCs manufactured at a nominal density of 800

kg m^{-3}. At the 1:1 wood-to-plastic ratio (Plates 1a and 1b), both Gmelina arborea and Ceiba pentandra composites exhibited numerous interfacial gaps, fibre pull-outs, and microvoids. These defects indicate inadequate interfacial bonding between the lignocellulosic fibres and the LDPE matrix, resulting from the inherent incompatibility between hydrophilic wood fibres and hydrophobic polymers. The occurrence of these defects suggests poor stress transfer efficiency and increased susceptibility to moisture ingress.

A notable improvement in morphology was observed at the 2:1 ratio (Plates 1c and 1d). The polymer matrix appeared more continuous and fibre embedding became more pronounced. The reduction in void content indicates improved fibre–matrix interaction and better consolidation of the composite structure. Consequently, composites at this ratio are expected to exhibit enhanced dimensional stability and improved mechanical performance.

The most favourable morphology at 800 kg m^{-3} was observed in the 3:1 formulations (Figures 1e and 1f). The micrographs showed a highly compact and homogeneous structure characterized by nearly complete fibre encapsulation and minimal void formation. The fibres appeared firmly anchored within the polymer matrix, suggesting strong interfacial adhesion and efficient stress transfer. Such a morphology is associated with improved resistance to crack propagation, reduced moisture absorption, and enhanced durability against biological degradation.

SEM Analysis at 900 kg m^{-3}

The SEM micrographs obtained from composites manufactured at 900 kg m^{-3} (Plates 2a–f) showed an overall improvement in fibre dispersion and matrix continuity compared with those produced at 800 kg m^{-3}. At the 1:1 ratio (Plates 2a and 2b), fibres were more uniformly distributed within the polymer matrix and interfacial voids were less pronounced. Improved fibre encapsulation indicates enhanced compatibility between reinforcement and matrix, which contributes to better load transfer during mechanical loading.

Plates 2c and 2d (2:1 ratio) displayed a relatively dense and well-consolidated structure. Most fibres appeared aligned and partially encapsulated by the matrix, while only a few isolated voids were visible. The improved structural continuity observed in these formulations suggests enhanced dimensional stability and lower permeability to moisture. These characteristics are essential for extending service life in outdoor applications. However, at the 3:1 ratio (Plates 2e and 2f), fibre concentration increased considerably, resulting in localized fibre agglomeration and the reappearance of interfacial voids. Although fibre reinforcement was higher, insufficient polymer coverage limited interfacial adhesion. Such microstructural defects can reduce mechanical performance by impairing stress transfer and increasing moisture accessibility.

Comparative assessment of all six micrographs at 900 kg m^{-3} indicates that the 1:1 ratio provided the most balanced morphology with optimum fibre dispersion, minimal interfacial defects, and superior matrix continuity.

SEM Analysis at 1000 kg m^{-3}

The SEM micrographs of composites produced at 1000 kg m^{-3} (Plates 3a–f) demonstrate the effect of increased board compaction on microstructural development. At the 1:1 ratio (Plates 3a

and 3b), fibre pull-outs and interfacial gaps were still visible, indicating incomplete bonding in some regions despite the higher density. The observed fibre extraction cavities suggest that failure under loading may occur through fibre debonding.

The 2:1 ratio composites (Plates 3c and 3d) exhibited a much denser and more continuous polymer phase. Fibre dispersion was relatively uniform and void content was significantly reduced. The improved morphology suggests greater stiffness and enhanced dimensional stability because moisture pathways were minimized.

The best overall morphology was observed in the 3:1 composites (Plates 3e and 3f). SEM examination revealed a smooth and continuous polymer matrix with fibres deeply embedded within the matrix and almost complete absence of interfacial defects. The intimate contact between fibres and matrix indicates excellent mechanical interlocking and strong interfacial adhesion. Such a microstructure is highly desirable because it promotes efficient stress transfer, suppresses crack initiation, and improves long-term durability.

Influence of Wood Species

Across all densities and mixing ratios, composites reinforced with Gmelina arborea generally exhibited more uniform fibre distribution and stronger fibre–matrix adhesion than those reinforced with Ceiba pentandra. This observation corresponds with the superior physical properties, lower water absorption, and improved biodeterioration resistance recorded for Gmelina-based composites. The relatively denser anatomical structure of Gmelina fibres likely contributed to improve mechanical interlocking with the polyethylene matrix.

Relationship Between Morphology and Composite Performance

The SEM observations clearly explain the performance trends observed in the physical, mechanical, and durability evaluations. Micrographs characterized by fibre pull-outs, voids, and poor interfacial adhesion corresponded to higher water absorption and lower dimensional stability. Conversely, composites with compact structures, continuous polymer phases, and effective fibre encapsulation demonstrated improved resistance to moisture uptake, enhanced mechanical performance, and greater durability against fungal and termite attack.

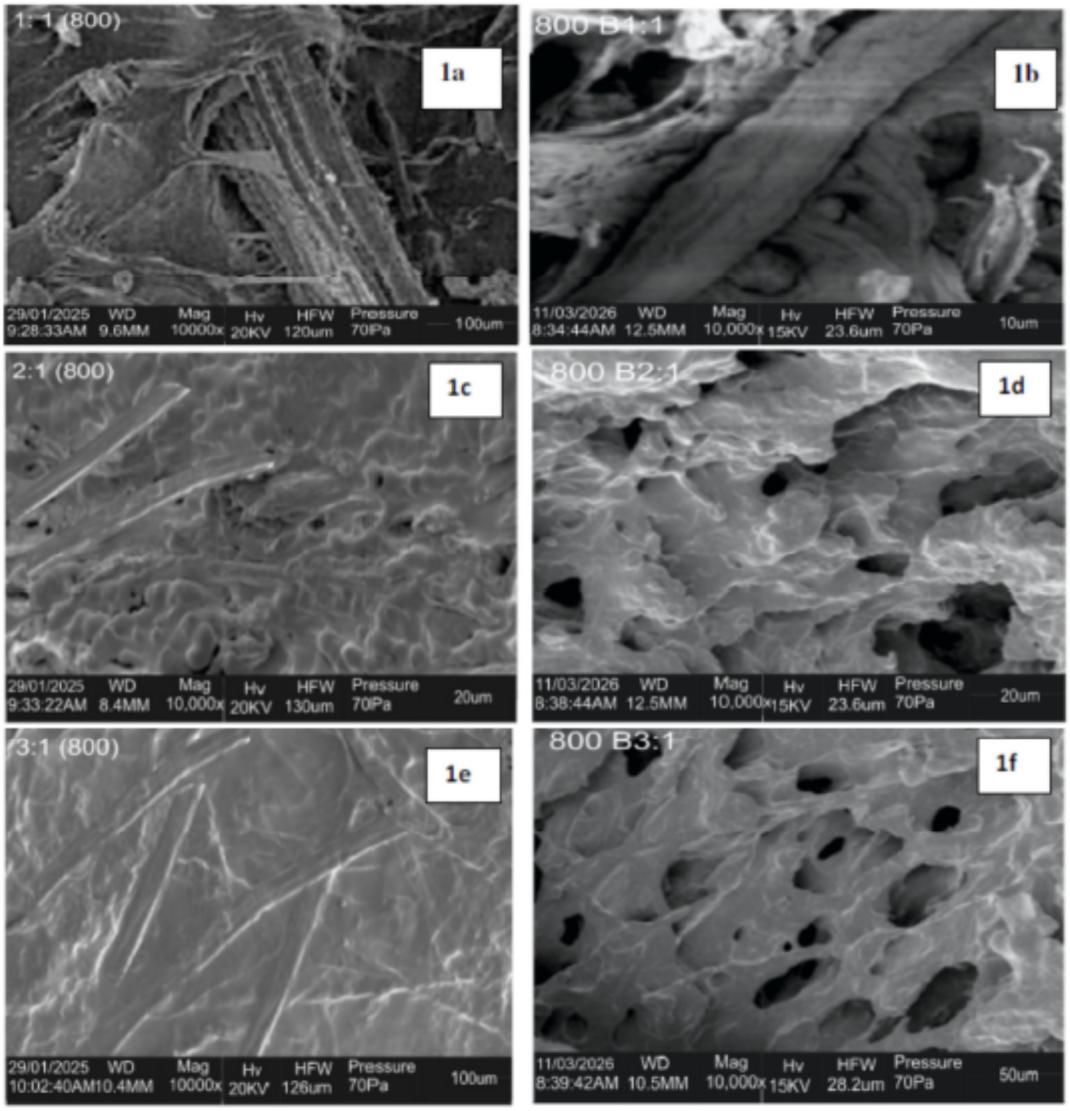


Fig. 1: SEM micrographs of WPCs produced at 800 kg m^{-3} showing the effect of wood species and wood-to-plastic ratio on fibre distribution and matrix continuity.
Fig. 1a: *Gmelina arborea* (1:1), Fig. 1b: *Ceiba pentandra* (1:1), Fig. 1c: *Gmelina arborea* (2:1), Fig. 1d: *Ceiba pentandra* (2:1), Fig. 1e: *Gmelina arborea* (3:1), Fig. 1f: *Ceiba pentandra* (3:1)

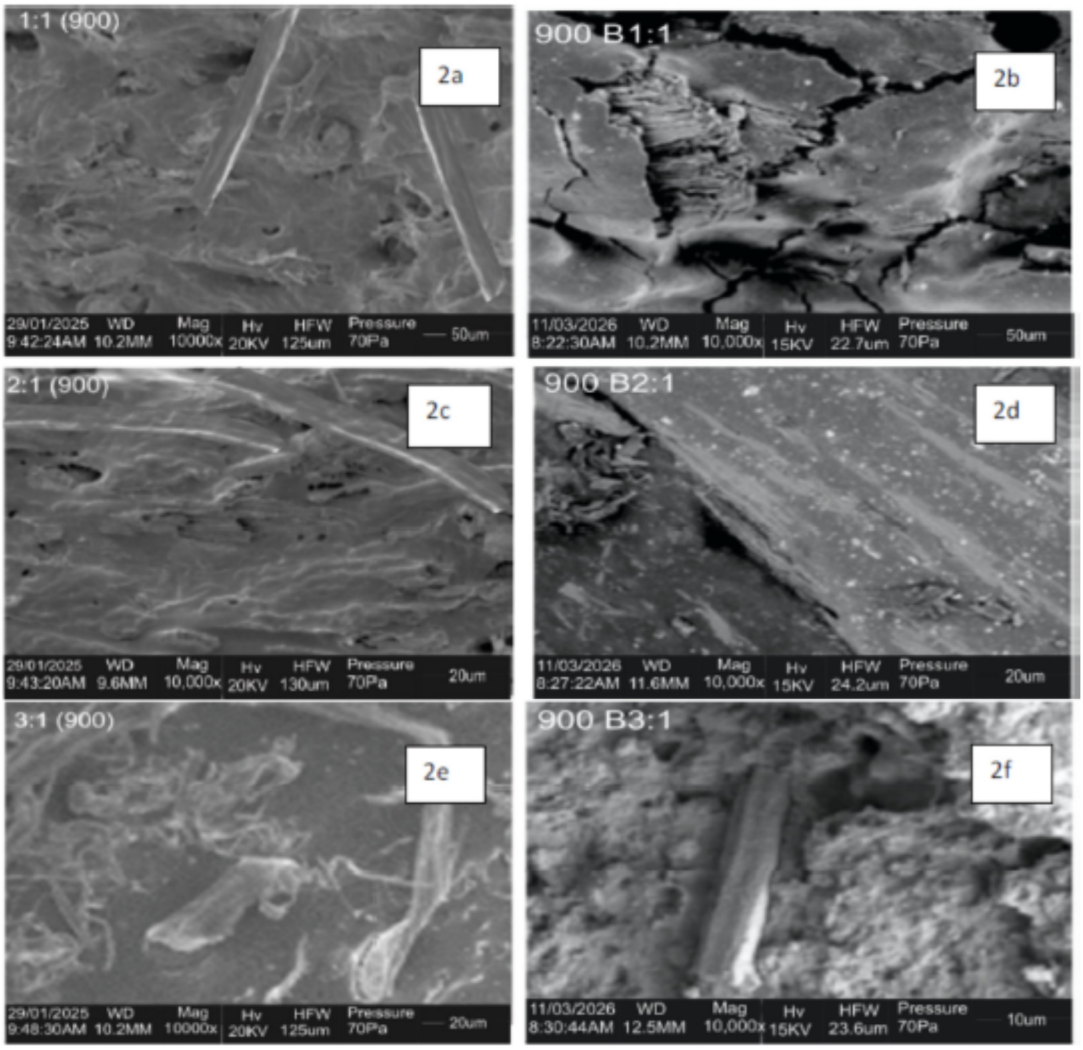


Figure 2: SEM micrographs of WPCs produced at 900 kg m^{-3} showing the effect of wood species and wood-to-plastic ratio on fibre distribution and matrix continuity.
Fig. 2a: *Gmelina arborea* (1:1), Fig. 2b: *Ceiba pentandra* (1:1), Fig. 2c: *Gmelina arborea* (2:1), Fig. 2d: *Ceiba pentandra* (2:1), Fig. 2e: *Gmelina arborea* (3:1), Fig. 2f: *Ceiba pentandra* (3:1)

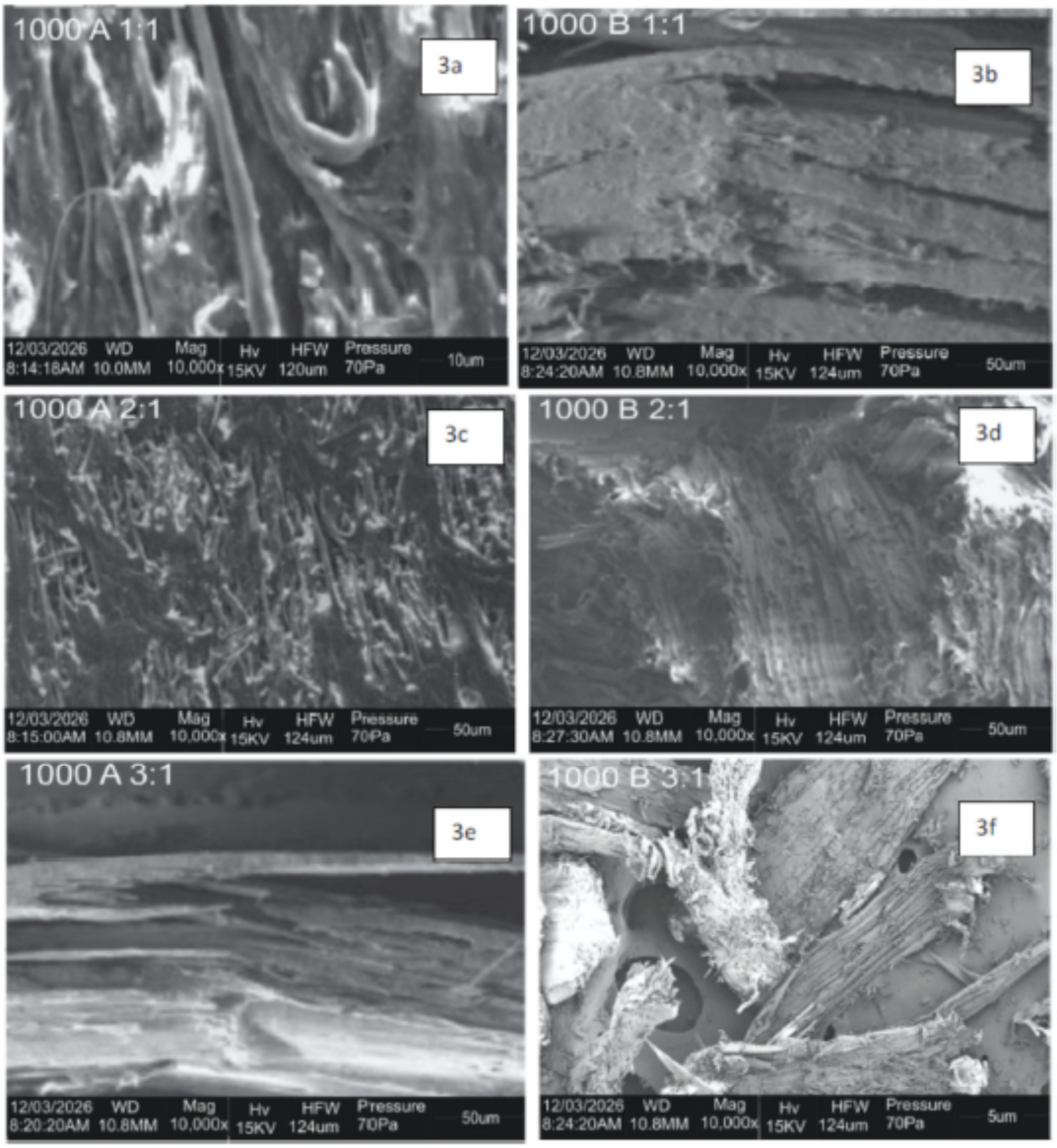


Fig. 3: SEM micrographs of WPCs produced at 1000 kg m^{-3} showing the effect of wood species and wood-to-plastic ratio on fibre distribution and matrix continuity.
Fig. 3a: *Gmelina arborea* (1:1), Fig. 3b: *Ceiba pentandra* (1:1), Fig. 3c: *Gmelina arborea* (2:1), Fig. 3d: *Ceiba pentandra* (2:1), Fig. 3e: *Gmelina arborea* (3:1), Fig. 3f: *Ceiba pentandra* (3:1)

The SEM observations obtained in the present study provide valuable insight into the relationship between composite microstructure and performance. Across all formulations, fibre dispersion, matrix continuity, interfacial adhesion, and porosity varied according to wood species, mixing ratio, and nominal density. These microstructural differences were reflected in the mechanical properties of the composites.

The occurrence of fibre pull-outs, interfacial gaps, and voids in some of the composites, particularly at lower densities

and less compact formulations, is characteristic of inadequate fibre–matrix bonding. Similar observations were reported by Stark and Rowlands (2003), who found that poor fibre encapsulation reduces stress-transfer efficiency between wood fibres and thermoplastic matrices, resulting in lower strength and increased moisture susceptibility. The SEM images from the present study showed that regions containing voids and partially embedded fibres corresponded with formulations that exhibited relatively higher water absorption and thickness swelling values.

The progressive reduction in void content observed as density increased from 800 to 1000 kg m^{-3} suggests that improved consolidation enhanced fibre–matrix contact. This observation agrees with the findings of Migneault *et al*. (2009), who reported that increasing composite compaction promotes intimate contact between wood particles and polymer matrices, thereby improving mechanical performance. Higher-density composites in the present study exhibited more continuous polymer phases and better fibre anchorage, which likely contributed to their superior durability and dimensional stability.

A notable feature of the SEM micrographs was the improvement in fibre encapsulation as matrix continuity increased. The polymer matrix was observed to penetrate irregularities on fibre surfaces and, in some cases, fill portions of the cell lumens. Such penetration creates mechanical interlocking, a phenomenon previously described by Clemons (2002) and Klyosov (2007) as a major contributor to load transfer within wood-plastic composites. Effective mechanical interlocking minimizes fibre debonding during loading and improves resistance to crack propagation.

The superior morphology observed in composites reinforced with Gmelina arborea compared with Ceiba pentandra may be attributed to inherent anatomical differences between the species. Gmelina arborea possesses a denser wood structure and thicker fibre walls than Ceiba pentandra, characteristics that may improve mechanical anchorage within the polyethylene matrix. Similar relationships between wood density and composite performance have been reported by Onilude and Ogunsanwo (2002) and Klyosov (2007), who observed that denser hardwood fibres generally produce composites with improved stiffness and dimensional stability. The present findings therefore suggest that wood anatomical characteristics play a significant role in determining fibre–matrix compatibility.

The influence of wood-to-plastic ratio observed in this study also corresponds with previous reports. At lower wood contents, the matrix was sufficient to effectively coat and encapsulate wood particles, producing relatively homogeneous microstructures. However, as wood loading increased, fibre agglomeration and matrix discontinuities became more evident. Similar trends were reported by Ashori (2008) and Adhikary *et al.* (2008), who noted that excessive wood loading often leads to insufficient matrix coverage, resulting in poor interfacial adhesion and increased moisture uptake. Water entering these regions can interact with accessible hydroxyl groups in cellulose and hemicellulose, leading to swelling of the lignocellulosic phase and subsequent dimensional instability. The SEM observations therefore provide a direct explanation for the water absorption and thickness swelling trends obtained in

the physical property evaluation. Similar relationships between morphology and moisture behaviour have been reported by Taib *et al*. (2010) and Bouafif *et al*. (2009)**.**

Overall, the SEM evidence demonstrates that composite performance is fundamentally governed by microstructural quality. Formulations exhibiting homogeneous fibre distribution, effective fibre encapsulation, strong interfacial adhesion, and minimal porosity consistently showed superior physical, mechanical, and durability characteristics. These observations are consistent with the findings of Stark and Berger (1997), Migneault *et al*. (2009), Ashori (2008)**,** and Klyosov (2007)**,** all of whom emphasized the importance of optimizing fibre–matrix interactions in the development of high-performance wood-plastic composites.

Conclusion

The Scanning Electron Microscopy (SEM) micrographs demonstrated that density, wood species, and wood-to-plastic ratio significantly influenced fibre distribution, matrix continuity, interfacial bonding, and void formation. Composites manufactured at higher densities generally exhibited more compacted structures, improved fibre encapsulation, and reduced porosity compared with those produced at lower densities.

Among the wood species investigated, Gmelina arborea produced composites with superior fibre–matrix interaction and more homogeneous microstructures than Ceiba pentandra. The improved morphology observed in Gmelina-based composites contributed to their enhanced dimensional stability, mechanical performance, and durability characteristics.

The SEM images further demonstrated that microstructural refinement directly influences composite performance. Composites characterized by strong fibre anchorage, continuous polymer matrices, and low void content exhibited improved resistance to moisture penetration, biological degradation, and mechanical failure. Conversely, fibre pull-outs and interfacial gaps were associated with reduced load-transfer efficiency and greater susceptibility to environmental deterioration.

This study confirms that optimization of composite morphology is essential for maximizing the performance of wood-plastic composites produced from tropical hardwood residues and recycled plastics. The utilization of Gmelina arborea residues and recycled LDPE therefore represents a promising approach for developing sustainable, durable, and high-performance composite materials for structural and non-structural applications.

References

Adhikary, K.B., Pang, S. and Staiger, M.P. (2008). Dimensional stability and mechanical behaviour of wood-plastic composites based on recycled and virgin high-density polyethylene. *Composites Part B: Engineering*, 39(5): 807–815. https://doi.org/10.1016/j.compositesb.2007.10.005

Ashori, A. (2008). Wood-plastic composites as promising green-composites for automotive industries. *Bioresource Technology*, 99(11): 4661–4667. https://doi.org/10.1016/j.biortech.2007.09.043

Ayrilmis, N., Kaymakci, A. and Ozdemir, F. (2011). Physical, mechanical, and morphological properties of

wood plastic composites manufactured from waste furniture sawdust and recycled polyethylene. *Materials and Design*, 32(10): 5124–5131. https://doi.org/10.1016/j.matdes.2011.03.029

Bouafif, H., Koubaa, A., Perré, P. and Cloutier, A. (2009). Effects of fiber characteristics on the physical and mechanical properties of wood plastic composites. *Composites Part A: Applied Science and Manufacturing*, 40(12): 1975–1981. https://doi.org/10.1016/j.compositesa.2009.06.003

Clemons, C.M. (2002). Wood-plastic composites in the United States: The interfacing of two industries. *Forest Products Journal*, 52(6): 10–18.

Fabiyi, J.S. and McDonald, A.G. (2014). Effect of wood species on property and weathering performance of wood plastic composites. *Composites Part A: Applied Science and Manufacturing*, 67: 1–10. https://doi.org/10.1016/j.compositesa.2014.08.004

Klyosov, A.A. (2007). *Wood-Plastic Composites*. Wiley-Interscience, Hoboken, New Jersey. 698-736 pp. ISBN 978-0-470-14891-4. DOI: 10.1002/9780470165935

Lu, J.Z., Wu, Q. and McNabb, H.S. (2000). Chemical coupling in wood fibre and polymer composites: A review of coupling agents and treatments. *Wood and Fiber Science*, 32(1): 88–104.

Migneault, S., Koubaa, A., Erchiqui, F., Chaala, A., Englund, K., Wolcott, M.P. and Krause, C. (2009). Effects of processing method and fibre size on the structure and properties of wood-plastic composites. *Composites Part A: Applied Science and Manufacturing*, 40(1): 80–85. https://doi.org/10.1016/j.compositesa.2008.10.004

Onilude, M.A. and Ogunsanwo, O.Y. (2002). Strength properties of selected Nigerian timber species. *Journal of Tropical Forest Products*, 8(1): 45–54.

Oriire, L.T., Aina, K.S., Adiji, O.A. and Adebisi, A.A (2024). Assessment of Properties of Wood Plastic Composite Reinforced With Wood Fibre. *Nigerian Agricultural Journal,* 55(2): 296-301.

Stark, N.M. and Berger, M.J. (1997). Effect of species and particle size on properties of wood-flour-filled polypropylene composites. Proceedings of the Functional Fillers for Thermoplastics Conference, 134–143.

Stark, N. M., and Rowlands, R. E. (2003). Effects of wood fibre characteristics on mechanical properties of wood/polypropylene composites. *Wood and Fiber Science*, 35(2): 167–174.

Taib, R.M., Rozman, H.D., Ishak, Z.A.M. and Ahmad, Z. (2010). Water absorption and dimensional stability of wood-plastic composites. *Journal of Reinforced Plastics and Composites*, 29(2): 219–227.

Wolcott, M.P. and Englund, K. (1999). A technology review of wood-plastic composites. University of Washington, College of Forest Resources.