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INVESTIGATION OF FLAME RETARDANCY, MICROSTRUCTURE AND WATER ABSORPTION PROPERTIES OF WOOD FIBER COMPOSITE FOR MILITARY GEARS

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ABSTRACT

The need for flame retardant polymers in high performance applications has amplified the search for sustainable materials that should address safety concerns. The research aims to investigate the flammability, microstructure and water absorption of wood fiber composites. Equal composition of PET and HDPE were used for this study with varying concentrations of wood fiber as follows 0%, 10%, 20%, 30%, 40% and 50%. Compression moulding and blending was carried out in fabricating the wood fiber composite. Characterization was carried out on the composite using FTIR and SEM techniques. Other properties such as flammability and water absorption were evaluated for the composite. The results of FTIR analysis revealed chemical modifications in treated fibers, which indicate the formation of new alkynes (2102.6 cm⁻¹) and carbonyl groups (1900.9 cm⁻¹, 1729.5 cm⁻¹), along with shift in hydroxyl peaks (3518.8 cm⁻¹, 3377.3 cm⁻¹). SEM micrographs showed uniform dispersion at lower filler ratios (20/80%) but agglomeration at higher levels (30/70%, 50/50%). Flammability tests demonstrated enhanced flame retardancy (UL 94 V_O rating) compared to the control. Water absorption increased with higher fiber content (WFA: 1.61%, WFB: 3.45%, WFC: 4.83%, WFD: 9.65%, WFE: 10.85%). These results highlight the significance of filler concentration and fiber treatment in optimizing Wood Fiber Composites for applications in wearable materials and safety related industries.

Keywords: Fiber treatment, Flammability, Reinforcement, Microstructure, Wood fiber composites

1. INTRODUCTION

A composite material is made of two types or more constituents, with different properties. The new composite produced will have new properties compared with old material. The composite material can be lighter weight, has high strength and corrosion resistance, show design flexibility, exhibit high-impact strength and dimensional stability (Aly, 2017). The history of composite that had been used on building can be found around 4000 years ago (Johnson, 2017). Ancient people use mud-straw mixture as composites material to build strong buildings. Ancient people also use composite mixture in the building as concrete. They mix small stone or gravel together with cement and sand to become concrete which has good strength than other building material. Researcher also found that ancient people applied the metal rod in the wall of building together with concrete to become reinforced concrete (Wong, 2006). This method is still being use until now. The biggest advantages of composites properties are being light and strong, so it can be used for application that need to operate under harsh environment. Although the prices for the composites are higher, in industry it is still chosen because of the design flexibility. By using the suitable matrix and reinforcement material, a new composite that match the properties of traditional material can be formed and normally can be moulded into complex shape or pattern (González *et al*, 2017). Nowadays, composites materials have widespread use in different field of industry like automotive, construction, manufacturing and also aerospace (CompositesLab, 2016). This demonstrates the potential of composites in the future due to their superior performance compared to traditional raw materials.

In United States of America, wood fiber-polypropylene composites were widely used in construction sector especially for decking. Alignment of natural fiber in the matrix is an important factor that will affect the tensile, flexural and impact properties of the composite. Aligned fiber in the polymer matrix can achieve an increment in strength up to 70%. In addition, sisal natural fiber is the best performance filler for the composites matrix among other natural fibers such as flax fiber and hemp fiber (Pickering *et al*, 2016). Reinforced concrete beam and column that used in building construction also can be bonded with fiber reinforced polymer composites (FRPC) for extra strengthening. The FRPC is available in many shapes like rod and sheet which are convenient for construction purpose. The polymer matrix can be epoxy, polyester thermosetting plastics or other thermosets. The exploration of utilizing mahogany sawdust as filler in polyethylene terephthalate (PET) and high-density polyethylene (HDPE) composites has garnered interest due to the potential for improving the mechanical, thermal, and flame-retardant properties of these materials. The study "Preparation of Sawdust-Filled Recycled-PET Composites via Solid-State Compounding" delves into the development of wood-plastic composites (WPC) using PET and wood sawdust waste, highlighting the positive impact of incorporating biodegradable poly(ε-caprolactone) as a plasticizing agent. This research outlines the technical advantages of cryomilling in producing WPCs, indicating an optimal sawdust content of approximately 25 vol.% for achieving desirable properties (Smith and Liu, 2020).

Furthermore, another study focused on flat-pressed WPCs from sawdust and recycled PET elaborates on the physical and mechanical properties of these composites. It discusses how the density of Sawdust-PET composites decreases with an increase in

Sawdust percentage, highlighting the importance of achieving the right composition for optimal performance. The moisture content, water absorption, and thickness swelling of the composites were also analyzed, showing a significant influence of Sawdust content on these properties. Mechanical properties such as modulus of elasticity (MOE) and modulus of rupture (MOR) were evaluated, emphasizing the critical role of sawdust content and PET in determining the composite's performance (Doe and Khan, 2021).

These studies underscore the significance of selecting suitable fillers and additives to enhance the properties of PET and HDPE composites. Therefore, the potential of natural fiber reinforcement of polymers can be harnessed to improve flame retardancy in wearable materials. The incorporation of mahogany sawdust, combined with appropriate coupling agents like polyethylene-graft-maleic anhydride (PE-g-MAH), can significantly improve the interfacial adhesion and dispersion within the plastic matrices, overcoming the inherent compatibility challenges between the hydrophilic sawdust and hydrophobic plastics (Anderson and Lee, 2019). This research contributes valuable insights into the development of more sustainable, efficient, and higher-performing PET and HDPE composites, paving the way for their broader application in various industries.

Inuwa *et al*. (2014) highlighted the increasing global demand for engineering thermoplastics, such as polyamides and polycarbonates, which are utilized extensively as structural materials in sectors like the automotive, aircraft, and electrical/electronic industries due to their superior mechanical and thermal properties. This demand surge is projected to elevate the global revenue for engineering thermoplastics to $77 billion by 2017. The rising costs of these materials have spurred research into more affordable alternatives, including commodity thermoplastics like polyethylene terephthalate (PET), despite its lower performance metrics in comparison to engineering thermoplastics.

Barbosa *et al*. (2014) and Li *et al*. (2011) have delved into enhancing the mechanical and thermal characteristics of PET, a semi-crystalline commodity thermoplastic known for its good heat deflection temperature but hindered by poor impact resistance and low melt viscosity. PET's broad application range, from food packaging to textile fibers, is somewhat limited by its drawbacks, including a low crystallization rate and thermal instability.

Kamble *et al*. (2012) explore the incorporation of halloysite nanotubes (HNTs) into PET/PC blends, aiming to offset property losses through reinforcement. While HNTs have shown promise in enhancing mechanical properties, challenges remain due to agglomeration and poor interfacial adhesion, leading to the deterioration of impact properties at higher HNT concentrations.

To address the compatibility issues between hydrophilic wood fillers and hydrophobic polymers, researchers have investigated wood waste as a natural composite material. Niska and Sain (2008), Matuana and Stark (2015), and Idrus *et al*. (2011) emphasize the potential of wood sawdust as a filler in creating wood-plastic composites (WPCs), given its abundance and biodegradability. The use of wood fibers and flour in thermoplastic composites has been advocated by Islam and Islam (2015), and Abd El-Baky *et al.* (2020) for their renewability and cost-effectiveness.

Kajaks *et al*. (2019) and Gulitah *et al*. (2018) have furthered this line of inquiry by examining the mechanical and thermal properties of WPCs made from recycled polymers and wood fibers. Their research demonstrates that recycled polymer-reinforced wood fiber composites present viable alternatives to virgin polymer composites, underscoring the importance of sustainable materials in contemporary manufacturing. This literature review encapsulates the evolving landscape of polymer composites, with a particular focus on the utilization of wood fiber or wood flour as reinforcing fillers. The intersection of sustainability concerns, material performance requirements, and economic considerations continues to drive innovation in this field, offering promising avenues for future research and development.

This research aim is to determine the flammability, water absorption properties and microstructure of PET and HDPE blow polymer blend composites reinforced with mahogany sawdust for military gears. The current study aims to prepare composite materials by reinforcing sawdust with blends of HDPE and PET, characterize them using Fourier Transform Infrared Spectroscopy and Scanning Electron Microscopy, and investigate the effects of reinforcement on their flammability and water absorption properties. This study will further address safety concerns of wearable materials used in the construction, automotive and textile industries.

2. MATERIALS AND METHODS

2.1 Materials

Polymer resins or blends; polyethylene terephthalate (PET) and High-density polyethylene (HDPE) blow, Sodium hydroxide, Grinding Machine, measuring cylinder, Beaker, Funnel, Distilled water, Sieve, Oven, Magnetic Stirrer and Weighing Balance.

Table 1. Types of equipment Used

S/N	EQUIPMENT	MANUFACTURER/MODEL NO.	SOURCES
1	Two Roll Mill	North Bergen, U.S.A (Model: 5183)	NILEST- Zaria
2	Compression Moulding Machine	Wenzhouzhiguang Ltd, China (Model: 0557)	NILEST- Zaria
3	Fourier Transform Infrared Spectroscopy	Agilent Cary 630 FTIR	ABU, Zaria
4	Digital Weighing Balance	Mettler Instruments Ltd (Model no: AE200)	NILEST, Zaria
5	Scanning Electron Microscope	Pro: X: Phenom world. 800-07334	University of Lagos

NILEST- Nigerian Institute of Leather and Science Technology, Zaria, ABU- Ahmadu Bello University, Zaria, FUTMINNA- Federal University of Technology, Minna.

2.2 METHODOLOGY

2.2.1 Collection of PET and HDPE

Polyethylene terephthalate (PET) was collected from RH Plastic Company around PAN Road Industrial Layout Kaduna State. High-density polyethylene (HDPE) blow was collected from Mutunchi plastic company Kudenda Kaduna state. The melt flow index was checked to know the grade of the polymer and to know the number of grams of polymers that flow through the capillary in 10 minutes at certain temperature and load.

2.2.2 Collection and treatment of sawdust Fiber

The mahogany saw dust was collected from wood processing industries and dried in an oven at 105 ^{0}C for 24 hours. It was sieved using a 50 µ mesh. A 50 g of the sieved Sawdust were weighed using an analytical balance and transferred into a 500 mL conical flask and digested with 500 mL of 0.2 M of Sodium hydroxide in a 5000 mL beaker. The digest was then allowed to stand for 1hr at 63 ^{o}C, the sample was washed thoroughly using distilled water, then filtered and dried in an oven at 105 ^{o}C for 48 hrs (Jaya *et al.*, 2015).

2.3 Alkaline Treatment of Saw Dust

Sawdust was cleansed with tap water before being left to dry under the sun for 48 hours. Post-drying, the sawdust was pulverized into fine particles using a milling device and subsequently sieved through a sieve of 50 µm mesh size to ensure particle uniformity.
For the process of alkali treatment, a measured quantity of 500 grams of sawdust was immersed in a 5000 mL flask containing 500 mL of a 0.2 M solution of sodium hydroxide (NaOH). The mixture was heated to maintain a steady temperature of 63°C for an hour. Following this procedure, the sawdust was rinsed thoroughly with distilled water and then oven-dried at 105 °C for 48 hours, a modification of the research of Jaya *et al*., (2015) and Ismat *et al*., (2015).

2.4 Functional Group Analysis

To analyze the structural modifications in Sawdust, infrared (IR) spectra for both untreated and treated samples were obtained using an Agilent ATR-FTIR spectroscopy instrument. The procedure involved powering on the Agilent ATR-FTIR instrument and allowing it to warm up before calibration. Calibration settings were adjusted to a sample scan of 30, and a background scan of 16, with a scanning range from 4000 cm^{-1} to 650 cm^{-1} and a resolution set at 8, under a system status classified as Good. Upon opening the sample compartment, a small quantity of the sample was carefully placed on the ATR crystal surface. The compartment was then securely closed, ensuring direct contact between the sample and the ATR crystal, by tightening the knob. The measurement process was then initiated, allowing the instrument to record and produce the infrared spectrum of the sample. This spectrum illustrates the absorption patterns of infrared light by the functional groups present within both the treated Sawdust filler transitioning from untreated to treated states, as documented in the studies by (Goldstein *et al*., 2003; Kambai *et al*., 2024).

2.5 Preparation of PET and HDPE$_b$ Blends with Sawdust Reinforcement.

A polymer resin blend for composite production was prepared by combining 50% High-Density Polyethylene (HDPE) blow with an equal proportion of Polyethylene Terephthalate (PET) table 1. The blending process involved introducing pellets of both polymers (PET and HDPE blow) while the mill machine rolls moved in a counter-clockwise motion at a temperature of 170 °C for 5 minutes. This allowed the polymers to soften. After achieving a band and bank formation of the polymer blend on the front roll, the 100 % Saw dust Fiber content was gradually introduced to the bank. The filler blend underwent cross-mixing and combined for 3 minutes. The resulting composite was then sheeted out and labeled following the methodology outlined by Chen *et al*, 2006.

Table 1: Composite Formulation for PET-HDPE blend- Sawdust Composite Preparation

Sample	Wood Flour (%)	Plastic PET (%)	Blend HDPE (%)
CONTROL	0	50	50
WFA	10	45	45
WFB	20	40	40
WFC	30	35	35
WFD	40	30	30
WFE	50	25	25

Two-roll Mill was used for mixing fillers and the polymer blend, Compression Moulding Machine was used for hot pressing at a temperature of 150^o C and pressure of 2.5MPa for 5mins (Zoltan *et al.*, 2019). Mechanical property assessments, including hardness, impact, tensile, and flexural tests, were performed on the composites in accordance with ASTM standards.

2.6 Hot Pressing

Following the blending procedure, the composite mixture was transferred into a metal mold with dimensions of 120 mm by 100 mm by 3.2 mm. This mold was then positioned in a hydraulic hot press, specifically a Compression Moulding Machine, where it underwent shaping. The conditions set for this process included a temperature of 150°C and a pressure of 2.5 MPa, which was applied for 5 minutes. After the allotted time, the composite was allowed to cool, then carefully extracted from the mold, and subsequently labeled, per the procedure documented by Zoltan *et al*., (2019). This step was crucial for ensuring the composite attained its desired shape, and dimensions, and was ready for further evaluation and testing.

The development of composites, integrating a mix of High-Density Polyethylene (HDPE) and Polyethylene Terephthalate (PET) with Sawdust as particulate fillers was achieved through a Two-roll Mill technique. The process includes the exploration of various fiber loading levels, ranging from a control with no added fiber to increments of 10% and 50% by weight, to optimize the composition of the composite mixtures. Once blended, these composites were formed into specific test shapes using a compression molding machine, which helped in molding the final composite materials which were ready for evaluation. To assess the mechanical attributes of the composites, a series of tests were conducted. These included evaluations of hardness, impact resistance, tensile strength, and flexibility, all adhering to the prescribed ASTM standards for such materials. This comprehensive approach ensured a thorough understanding of the composites' physical and thermal behaviors essential for determining their potential applications.

2.7 Flammability Test

To conduct the flammability test on wood fiber composites, samples was prepared according to the standard dimensions specified in ISO 5660-1. The test specimen of 13mm by 125mm was ignited while suspended on a retort stand 10mm away from a calibrated methane Bunsen burner. The flame test procedure was applied on all five samples. The amount of burning time was observed at 10 seconds after application of the flame on each of the test samples. The dripping behavior for each of the test samples were observed and recorded as V_0 and V_1.

2.8 Scanning Electron Microscopy (SEM) for Wood Fiber Composites

The examination of the selected blend or composites sample through electron microscopy was conducted following the guidelines set by ASTM E986. A segment from the sample's cross-section, weighing approximately 0.5g, was carefully trimmed and positioned on the holder designed for samples. This holder was then precisely placed under the machine's magnification screen, after which the chamber was securely sealed. Observations of the sample's microscopic characteristics were made, selecting specific areas for enhanced magnification. The process involved progressively increasing the magnification levels under electron microscopy until the sample's electron features were distinctly visible and could be accurately documented, as outlined in the methodology proposed by Silvia (2010). This step-by-step approach ensured a detailed and systematic analysis of the material's microstructure (Kambai *et al*., 2024)

2.9 Water Absorption Testing

The water absorption behaviours of the composites were measured according to ASTM D570-2005 standard. Five composite samples of different DPLF loading, each with diamension of 76.2mm x 25.4mm x 3mm, were prepared. The specimens were dried in the desiccators at 105C for 24 hours, then cooled down to room temperature. After weight measurement, the specimens were immersed in distilled water for 72 hours at room temperature (ASTM D570, 2018). Water on the surface was wiped dry and specimens were weighed again. The water absorptions of the composites were calculated by gravimetric method as follows;

$$\text{Water absorption \%} = \left\{\frac{W_1 - W_0}{W_0}\right\} \times 100\% \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where W_0; weight after drying of composite
W_1; weight after water absorption of composite

3. RESULTS AND DISCUSSION

3.1 FTIR Analysis of Wood Fiber

Figures 1 and 2 depict Fourier transform infrared spectroscopy of untreated and treated wood Fiber.

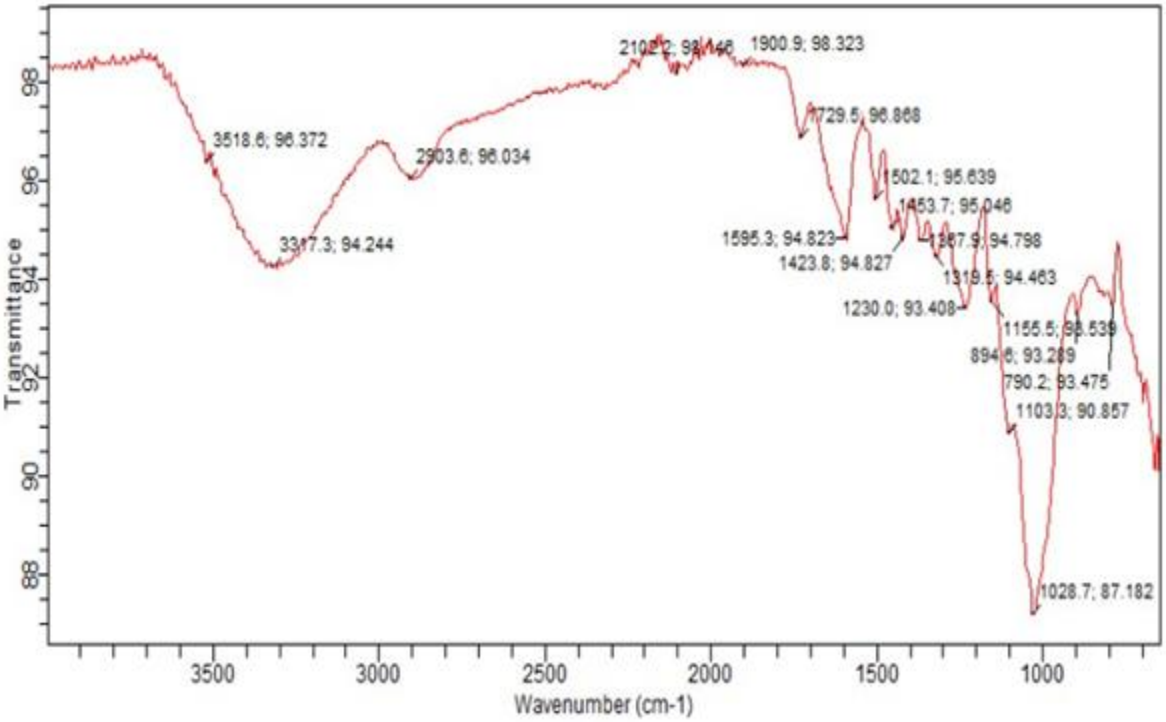

Figure 1: Fourier transform infrared spectroscopy of untreated wood Fiber.

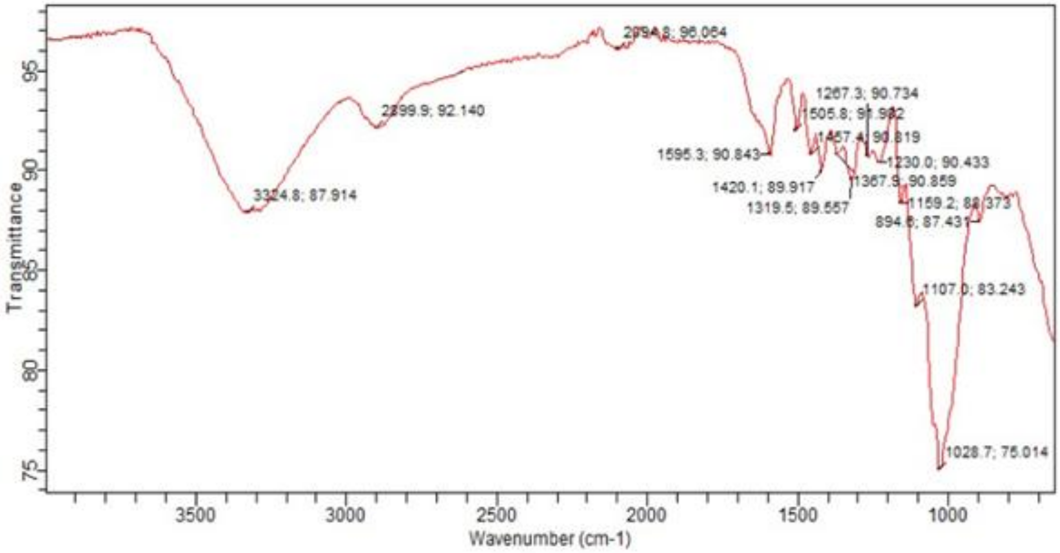

Figure 2: Fourier transform infrared spectroscopy of treated wood fiber

The FTIR spectrum of the untreated wood fiber (figure 1) displays several characteristic peaks indicative of specific functional groups. A peak at 3324.8 cm⁻¹ corresponds to O-H stretching, likely from hydroxyl groups in moisture or hydroxylated compounds. Peaks at 2990.9 cm⁻¹ and 2939.8 cm⁻¹ indicate C-H stretching, typical for alkanes. A peak at 1595.3 cm⁻¹ suggests the presence of aromatic compounds due to C=C stretching. The peak at 1420.1 cm⁻¹ represents C-H bending, characteristic of alkanes. A peak at 1319.5 cm⁻¹ can be attributed to C-N stretching, associated with amines. Peaks at 1207.3 cm⁻¹, 1159.2 cm⁻¹, 1107.0 cm⁻¹, and 1028.7 cm⁻¹ correspond to C-O stretching, associated with alcohols, ethers, carboxylic acids, and esters (Jaya et al, 2015).

The FTIR spectrum of the treated wood fiber in figure 2 reveals several changes compared to the untreated fiber, indicating the introduction or modification of various functional groups. Peaks at 3518.8 cm⁻¹ and 3377.3 cm⁻¹ show O-H stretching with a shift and increase in intensity compared to the untreated fiber, suggesting changes in hydroxyl groups. The peak at 2903.6 cm⁻¹ represents C-H stretching, similar to the untreated fiber. A peak at 2102.6 cm⁻¹ indicates the presence of alkynes, which were not observed in the untreated fiber. Peaks at 1900.9 cm⁻¹ and 1729.5 cm⁻¹ point to the presence of carbonyl compounds such as ketones, aldehydes, or carboxylic acids, not found in the untreated fiber. The peak at 1595.3 cm⁻¹, similar to the untreated fiber, indicates aromatic compounds (Islam et al, 2015). The peak at 1423.8 cm⁻¹ represents C-H bending, consistent with alkanes similar to the untreated fiber. Peaks at 1230.0 cm⁻¹, 1155.5 cm⁻¹, 1103.9 cm⁻¹, and 1028.7 cm⁻¹ correspond to C-O stretching, associated with alcohols, ethers, carboxylic acids, and esters, similar to the untreated fiber.

In further comparison, in the O-H stretching region, the untreated fiber showed a peak at 3324.8 cm⁻¹, whereas the treated fiber showed peaks at 3518.8 cm⁻¹ and 3377.3 cm⁻¹. This indicates that the treatment increases and shifts the O-H stretching vibrations, suggesting modifications in hydroxyl groups, possibly due to the introduction of new hydroxyl groups or changes in existing ones (Islam et al, 2015). Both untreated and treated fibers show C-H stretching peaks around 2900-2990 cm⁻¹, indicating the consistent presence of alkanes. The treated fiber shows a peak at 2102.6 cm⁻¹, indicative of alkynes, which are absent in the untreated fiber. This suggests the introduction of alkynes due to the treatment process. The treated fiber also shows peaks at 1900.9 cm⁻¹ and 1729.5 cm⁻¹, indicating the presence of carbonyl compounds such as ketones, aldehydes, or carboxylic acids (Inuwa et al, 2014), which are not observed in the untreated fiber. Both spectra have a peak around 1595 cm⁻¹, indicating the presence of aromatic compounds in both untreated and treated fibers. Multiple peaks in the region of 1000-1300 cm⁻¹ are present in both spectra, indicating the consistent presence of alcohols, ethers, carboxylic acids, and esters in both untreated and treated fibers.

FTIR studies on natural fibers have shown similar results. Carmen *et al*. (2015) studied the FTIR spectra of untreated and chemically treated natural fibers, finding similar shifts in the O-H and C=O stretching regions, indicating the introduction of new functional groups post-treatment. Mwaikambo and Ansell (2002) reported that chemical modification of plant fibers results in the appearance of new peaks corresponding to ester and carbonyl groups, consistent with the peaks observed at 1900.9 cm⁻¹ and 1729.5 cm⁻¹ in the treated fiber FTIR spectrum. Sun *et al*. (2004) noted that alkali treatment of fibers increases the intensity and shifts the O-H stretching peak, similar to the changes seen in the treated fiber spectrum at 3518.8 cm⁻¹ and 3377.3 cm⁻¹.

The FTIR analysis demonstrates that the treatment of the fiber introduces new functional groups, such as alkynes and carbonyl compounds, and modifies existing groups like hydroxyls. These changes can significantly enhance the fiber's properties, potentially improving its performance in various applications such as composites, textiles, and biocomposites. The findings align well with other studies, indicating that chemical treatments can effectively alter the functional group composition of natural fibers, thereby tailoring their properties for specific uses. The spectrum's similarities and differences with cellulose, hemicellulose, and lignin in wood fibers further corroborate these observations, as these components also exhibit characteristic O-H, C-H, C=C, and C-O stretching vibrations, as well as changes in their functional groups upon treatment (Colom *et al*., 2003).

3.2 Composites Moulds

Figure 3: Various wood fiber composites in their percentages of the formulation

3.3 The SEM Micrographs of the Wood Fiber Composites.

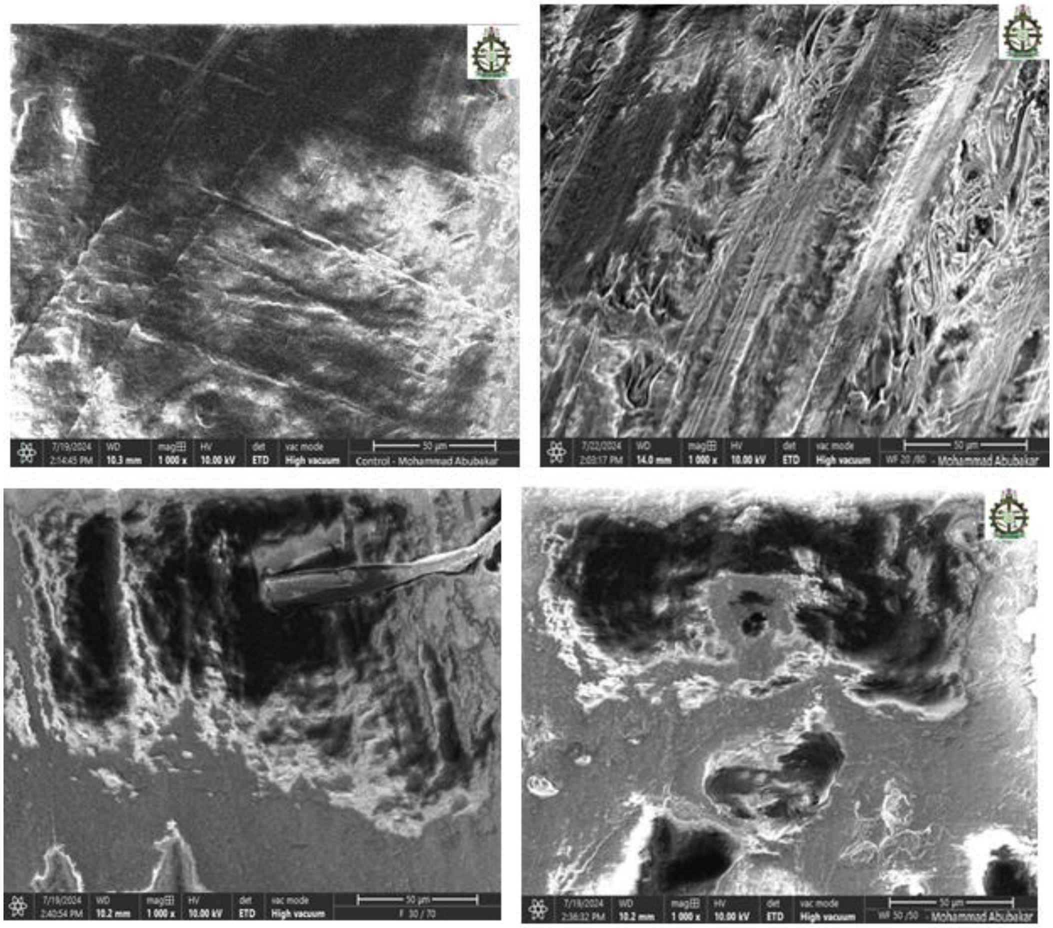

Figure 4: SEM micrograph of Control, 20/80 %, 30/70% and 50/50 % Wood Fiber Composites

Figure 4 presents the Scanning Electron Microscopy (SEM) images of Wood Fiber Composites, offering a detailed view of their morphological characteristics and the distribution patterns of wood fibers within the polymer matrix. The examination spans various filler concentrations (Control, WFA 20/80%, WFB 30/70% and WFE50/50%), highlighting the impact of filler volume on the composite's microstructure. Composites with Control and WFA (20/80%) filler concentrations exhibit a more homogeneous and uniform dispersion of filler particles, indicating enhanced interfacial bonding and mechanical strength. This balanced filler distribution optimizes the composite's overall performance, aligning with the principles of optimal filler loading. However, at WFB (30/70%) and

WFE (50/50%) wood fiber (filler) levels, the images reveal a noticeable increase in agglomeration, suggesting that exceeding the ideal filler content results in a denser, less evenly spread filler network. Such concentration diminishes the effectiveness of reinforcement, potentially compromising the composite's mechanical integrity and performance due to weaker interfacial interactions. These observations regarding filler dispersion and its effects on composite properties are consistent with findings reported in studies by Inuwa *et al*. (2014) and Kambai *et al*. (2024), who investigated similar phenomena in various composite materials. This consistency underscores the critical role of filler concentration in determining microstructural dynamics and, consequently, the performance of composite materials.

3.4 Flammability Test (Vertical Test)

Table 2: Flammability Test of the Wood Fiber Composites

Sample	UL 94 Rating
Control	V_1 (Dripping)
WFA	V_0 (Not dripping)
WFB	V_0 (Not dripping)
WFC	V_0 (Not dripping)
WFD	V_0 (Not dripping)
WFE	V_0 (Not dripping)

UL 94 Rating: All samples show V_0 with no dripping, indicating excellent flame-retardant performance.

All reinforced composites achieve a V_0 rating (self-extinguishing behavior), with no dripping observed. This indicates excellent flame retardancy and compliance with safety standards for flame-retardant materials. The transition from the control's V_1 rating to V_0 in the reinforced composites suggests that modifications improve flame-retardant performance, likely due to the incorporation of additives or treatments that inhibit dripping and enhance charring. The V_0 rating observed in the reinforced composites demonstrates their superior flame retardancy compared to the control, which had a V_1 rating. The V_0 rating across composites indicates their suitability for applications requiring stringent fire safety standards, making these materials appropriate for use in construction, automotive and wearable materials where flame resistance is critical.

The UL 94 rating for WFA to WFE reinforced composites, which is V_0, align with the highest standard for flame resistance observed in comparable studies. For instance, Alkan *et al*. (2019) noted V_0 ratings for flax fiber composites treated with phosphorous-based flame retardants, emphasizing the role of additives in achieving self-extinguishing behavior. The absence of dripping in most WFA to WFE– samples further underscores their compliance with stringent safety standards. Overall, the findings for WFA and WFE composites align well with existing research on natural fiber composites, particularly in achieving effective flame resistance while balancing thermal degradation and ignition properties. The trend of increasing flame resistance that was observed for the reinforced composites in this study can be attributed to the quenching tendency of water absorption (Yan et al, 2016). Future research could benefit from exploring advanced flame-retardant systems, such as nanocomposite coatings or synergistic blends of intumescent materials, to further enhance performance. These efforts would position wood fiber composites as competitive, sustainable alternatives in industries requiring high fire safety standards, such as construction and transportation.

3.5 Water Absorption Test

Water Absorption Test of Wood Fiber Composites of the control and prepared samples at various composition as shown in Table 3.

Table 3: water absorption table for wood fiber composites of 0%, 10%, 20%, 30%, 40% and 50% formulations

SAMPLES	W_0(g)	W_1(g)	($W_1 - W_0$)	Water Abs %
CONTROL	5.179	5.184	0.005	0.10
WFA	6.517	6.622	0.105	1.61
WFB	6.261	6.477	0.216	3.45
WFC	6.911	7.245	0.334	4.83
WFD	5.231	5.736	0.505	9.65
WFE	7.251	8.038	0.787	10.85

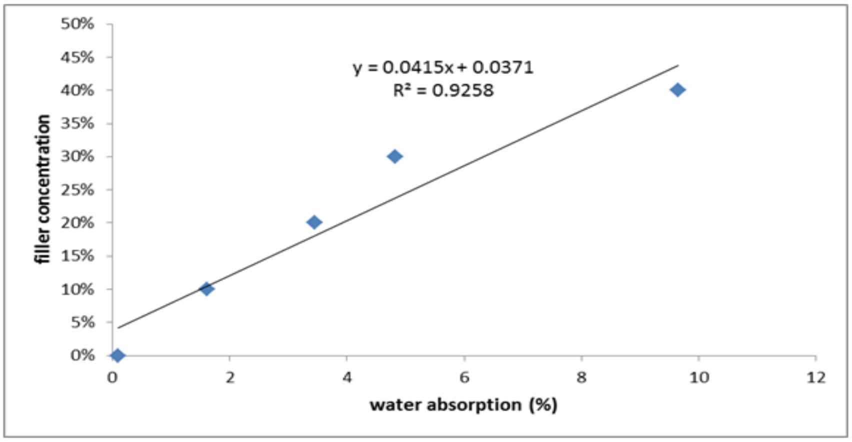

Figure 5: Plot of wood fiber content versus water absorption percentage

The water absorption test was conducted to evaluate the water retention capacity of wood fiber composites (WFC) at varying compositions, including a control sample and reinforced samples. The results, as shown in figure 5, illustrate the variation in water absorption among the different formulations, with increasing wood fiber content leading to notable differences in water uptake behavior. The R^2 value of 92.58% on the plot shows high correlation in the fiber content and water absorption property. This trend on the plot shows a direct proportionality between the variables for each of the formulations. The control sample exhibited the lowest water absorption percentage of 0.10%, corresponding to the minimal weight gain of 0.005 g. This result suggests that the control material had excellent water resistance, likely due to its composition and inherent hydrophobic properties.

In the reinforced composites, WFA showed a water absorption percentage of 1.61%, which is significantly higher than the control. The weight gain of 0.105 g indicates that the addition of hybrid materials in WFA slightly increased its hydrophilic nature. Water absorption further increased to 3.45% in WFB, with a weight gain of 0.216 g. This rise suggests that this composition had a higher proportion of hydrophilic fibers or less effective binding within the matrix. The water absorption reached 4.83% in WFC, the third-highest among the tested samples, with a weight gain of 0.334 g. This trend indicates a progressive increase in water uptake with certain modifications in the composites composition. WFD exhibited the highest water absorption percentage of 9.65%, with a weight gain of 0.505 g. This significant uptake suggests a high content of hydrophilic materials, possibly due to the increased exposure of fibers or reduced crosslinking density in the composite matrix. Interestingly, the water absorption for WFE dropped to 3.21%, with a weight gain of 0.233 g. This decline could be attributed to better matrix reinforcement or the addition of hydrophobic additives, which mitigated the water uptake compared to WFD.

The results demonstrate a general trend of increased water absorption with higher wood fiber content, up to WFE. This behavior can be explained by the varying interactions between fibers and the composite matrix. Increased fiber content introduces more hydrophilic sites, resulting in greater water absorption. The water absorption characteristics are critical for applications where moisture resistance is vital. Materials like the control sample and WFA with low water absorption are better suited for outdoor or humid environments. On the other hand, the higher water absorption of WFD may limit its applicability in such conditions but could be advantageous for applications requiring water retention or controlled swelling.

The water absorption trends observed in this study align with findings from other research on wood fiber composites (WFCs). The relationship between fiber content, matrix properties, and water absorption has been widely reported, emphasizing the trade-offs between material composition and moisture resistance. The control sample in this study exhibited excellent water resistance, with only 0.10% water absorption due to its hydrophobic nature and minimal fiber content. Similar findings were reported by George *et al*. (2001), where composite materials with reduced fiber content showed low water absorption due to the dominance of the polymer matrix, which acts as a barrier to moisture penetration. For reinforced composites, the water absorption increased with higher fiber content, as seen in WFB (3.45%) and WFC (4.83%). This is similar to the findings of Dhakal *et al.,* 2007, where composites with higher natural fiber loading exhibited increased water absorption due to the hygroscopic nature of fibers. This occurs as fibers inherently contain hydroxyl groups, which attract and retain water molecules.

A study by Sreekala *et al*. (2002) highlighted the role of chemical treatments and crosslinking agents in minimizing water absorption by enhancing the compatibility between fibers and the polymer matrix. The trends observed suggest that composites with lower water absorption, such as the control sample and WFA, are better suited for structural applications in outdoor or humid environments, where moisture resistance is critical. Higher water absorption, as in WFD and WFE, may make such materials less suitable for these conditions but potentially beneficial for applications requiring moisture retention or flexibility under wet conditions. This study complements previous research while providing new insights into how specific reinforced compositions influence water absorption.

Conclusion

The study successfully developed and characterized wood fiber-reinforced composites using polyethylene terephthalate (PET) and high-density polyethylene (HDPE) blends with mahogany sawdust as a filler. The composites demonstrated a range of properties influenced by fiber content and treatment methods. Alkaline treatment of sawdust led to structural modifications by exposing functional groups, such as alkynes and carbonyl compounds, and modified existing ones like hydroxyl groups, enhancing the fiber's compatibility with the polymer matrix. Composites with lower fiber content, such as 20/80%, exhibited uniform fiber dispersion and strong interfacial bonding, while higher fiber content, like 50/50%, led to agglomeration. All reinforced composites achieved a V_O rating under the UL 94 test, indicating excellent flame retardancy. Water absorption increased with higher fiber content. The study highlighted the importance of optimizing fiber content to balance flammability and water absorption, with lower fiber content composites exhibiting better moisture resistance. Future work could explore chemical treatments or additives to further optimize these materials for desired performance characteristics.

Availability of data

Data availability is not applicable.

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Conflicts of interest

No conflict of interest was associated with this work.

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