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Microstructural Characterization of Fibre Reinforced Polymer (FRP) Composite (Kenaf Fibre and Polyester Resin) for Structural Applications

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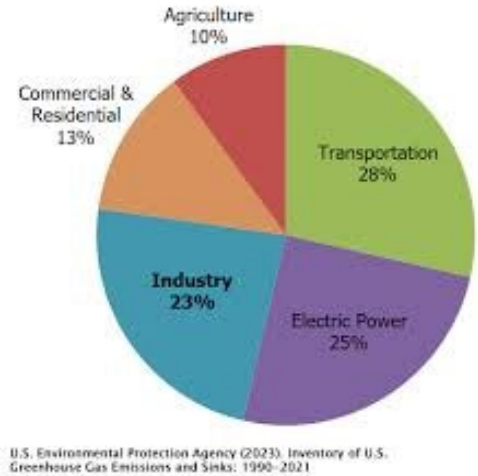
Abstract

Demand for sustainable, high-performance construction materials has driven interest in natural fibre–reinforced polymer (NFRP) composites. This study characterizes microstructure and thermal behaviour of polyester composites reinforced with powdered kenaf fibre at 0, 10, 20, 30 and 40 wt%. Composites were fabricated under controlled conditions and analyzed by FTIR, XRD, TGA/DTG, SEM and EDX to evaluate chemical interactions, crystallinity, thermal stability and morphology. FTIR identified hydroxyl, carbonyl and aromatic functional groups, indicating interfacial interactions between kenaf and polyester. XRD showed increasing crystallinity with higher fibre loading, implying greater structural ordering. TGA/DTG revealed enhanced thermal stability at moderate fibre contents, with optimal performance around 20–30 wt%, while stability declined at 40 wt%. SEM of pounded kenaf confirmed irregular, short fibres with rough fractured ends; untreated fibres showed surface impurities and relatively smooth areas consistent with partial hemicellulose and lignin removal. SEM of composites at 10 wt% displayed effective load transfer and strong kenaf–resin bonding. In contrast, composites with 20–40 wt% exhibited numerous fibre pull-outs, long pull-out lengths, interfacial gaps, poor wetting and weak adhesion, indicating diminished interfacial bonding at higher loadings. EDX quantified elemental composition of kenaf fibres (64.01% C, 34.05% O, 1.13% K, 0.30% S, 0.27% Ca, 0.24% Mg), confirming the presence of mineral elements that may influence composite behaviour. Overall, incorporation of kenaf significantly affects the chemical structure and thermal response of polyester composites. Results suggest an optimal kenaf content range (approximately 20–30 wt%) balancing improved crystallinity and thermal resistance with acceptable interfacial performance. These findings support the potential of kenaf–polyester composites as eco-friendly, cost-effective materials for structural applications, and provide guidance for their development in engineering and construction.

Keywords: *Kenaf fibre, polyester resin, FRP composites, chemical characterization, FTIR, TGA, XRD, SEM and EDX, structural applications.*

1.0. Introduction

Fibre Reinforced Polymer (FRP) composites have been widely recognized as advanced engineering materials composed of a polymer matrix reinforced with fibres to enhance mechanical, thermal, and chemical performance. The reinforcing fibres were reported to impart strength and stiffness, while the polymer matrix functioned as a binding medium that transferred applied loads and protected the fibres from environmental degradation. Previous studies had emphasized that the building and construction sector accounted for approximately 39% of global carbon emissions, largely due to energy-intensive material production and human activities such as transportation, deforestation, and power generation [1]–[4]. These emissions were linked to increasing greenhouse gas concentrations and global warming concerns.



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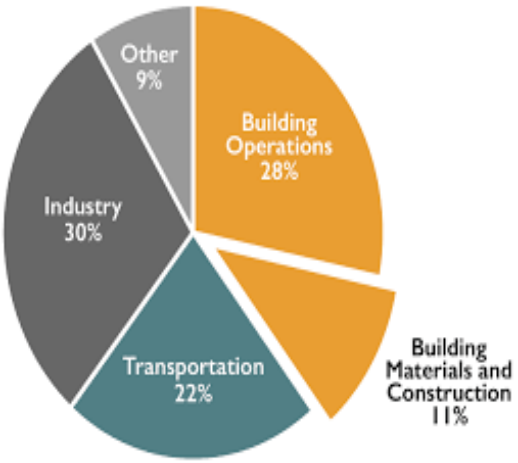

National GHG inventory report, 2000 - 2017

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Conventional construction materials such as steel, concrete, timber, and masonry had long been utilized due to their strength and reliability. However, it had been reported that these materials exhibited inherent limitations, including corrosion in steel, low tensile strength in concrete, and susceptibility to decay in timber. Additionally, their production processes were associated with high energy consumption and environmental degradation. In response, researchers had increasingly advocated for sustainable alternatives such as FRP composites, which were reported to possess lower ecological impact and improved durability [5], [6].

Recent investigations had highlighted the growing interest in natural fibre-reinforced polymer composites due to their sustainability, low cost, biodegradability, and availability. Among these, kenaf (Hibiscus cannabinus) had been identified as a promising reinforcement material due to its high cellulose content, low density, and favourable mechanical properties [7]. It had been reported that kenaf fibres consisted primarily of cellulose, hemicellulose, and lignin, which significantly influenced their structural integrity and interaction with polymer matrices.

Polyester resin, particularly unsaturated polyester, had been widely utilized as a matrix material due to its good mechanical properties, chemical resistance, and ease of processing. Studies had indicated that polyester exhibited strong adhesion characteristics and low water absorption, making it suitable for reinforcing natural fibres such as kenaf [8]. The combination of kenaf fibres and polyester resin had been reported to produce composites with enhanced strength, stiffness, and environmental performance. However, it had also been noted that the hydrophilic nature of natural fibres and the hydrophobic nature of polymer matrices often resulted in weak interfacial bonding. [9] reported that increasing scientific interest had been observed in natural fibre hybrid composites, driven by the need to improve mechanical performance and expand application areas. Their review indicated that although natural fibres exhibited lower strength compared to synthetic fibres, hybridization techniques had been extensively employed to enhance composite properties. They further noted that research efforts had focused on improving fibre-matrix adhesion, optimizing processing techniques, and reducing material variability and cost, while also identifying factors responsible for structural and mechanical failure. [10] had examined bast fibre-based hybrid composites and reported that materials reinforced with flax, hemp, and kenaf offered advantages such as reduced weight, improved impact resistance, and cost-effectiveness. However, they noted that these composites exhibited lower mechanical properties compared to glass and carbon fibre composites in structural applications. The authors emphasized that hybridization with high-performance fibres had significantly improved mechanical performance and expanded their applicability. [11] investigated kenaf-glass fibre reinforced polyester composites and reported that treated kenaf fibres exhibited superior tensile, flexural, and impact strength compared to untreated fibres. Their findings showed that chemical treatment enhanced interfacial bonding, while scanning electron microscopy revealed failure mechanisms such as fibre pull-out and debonding. The study concluded that hybridization and surface treatment significantly improved composite performance. [12] reviewed the development of kenaf fibre reinforced polyester composites and reported that these materials had gained attention due to their eco-friendliness, low cost, and good mechanical properties. They emphasized that interfacial adhesion between fibre and matrix played a critical role in determining tensile performance. The authors further noted that chemical modifications such as alkali treatment improved bonding and enhanced mechanical and morphological properties. [13] investigated kenaf and kapok fibre hybrid polyester composites and reported that hybridization improved tensile and impact strength compared to single-fibre composites. Their study indicated that equal proportions of kenaf and kapok fibres produced optimal mechanical performance, while SEM analysis confirmed improved fibre distribution and fracture behaviour. [14] had incorporated bamboo nanoparticles into kenaf fibre reinforced polyester composites and reported that the addition of 3% nanofillers improved bonding, wettability, and mechanical performance due to increased surface area. However, higher nanoparticle content resulted in agglomeration and reduced performance. The study also demonstrated that woven fibre structures enhanced interfacial adhesion compared to nonwoven configurations. [15] Had investigated alkali-treated banana and kenaf fibre hybrid composites and reported that chemical treatment improved strength, stiffness, and toughness. However, they noted that elastic modulus did not significantly increase. The study attributed improvements to reduced hydrophilicity and enhanced fibre-matrix compatibility, as confirmed by SEM analysis.

[16] provided a comprehensive review of hybrid natural fibre composites and reported that hybridization was an effective strategy for tailoring material properties by combining different fibre types within a single matrix. They highlighted the wide applications of such composites in aerospace, automotive, and civil engineering, while also identifying mechanical and structural failure mechanisms. [17] had evaluated kenaf fibre reinforced epoxy composites and reported significant improvements in stiffness and viscoelastic properties with increasing fibre content. Their findings indicated that composites with 30% kenaf fibre exhibited enhanced storage modulus and improved interfacial adhesion. Ballistic testing further demonstrated the potential of kenaf composites for advanced applications. [18] examined kenaf fibre reinforced PVB composites and reported that increasing fibre content up to 40% reduced tensile and flexural strength, although impact resistance remained relatively high. SEM analysis revealed various fracture mechanisms, highlighting the importance of optimizing fibre content. [19] had investigated sisal fibre reinforced polyester composites and reported that a 40% fibre content with specific stacking

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sequence provided optimal tensile, flexural, and impact strength. The study emphasized that proper fibre orientation significantly enhanced interfacial bonding and mechanical performance. [20] explored hybrid jute/kenaf/glass composites with nanofillers and reported significant improvements in tensile strength, modulus, and thermal stability. They noted that the addition of multi-walled carbon nanotubes enhanced composite performance, while SEM analysis revealed failure mechanisms such as fibre breakage and delamination. [21] had examined chemically modified kenaf fibre composites and reported that propionylation improved water resistance and mechanical properties. The optimized composite exhibited enhanced tensile and flexural strength, attributed to improved fibre-matrix bonding. [22] had reviewed kenaf fibre reinforced biocomposites and reported their suitability for marine applications due to their lightweight, biodegradability, and favourable mechanical properties. They emphasized that advances in manufacturing techniques had improved performance and expanded application areas.

[23] Had investigated kenaf fibre reinforced shape memory polymer composites and reported that mechanical properties improved with fibre content up to an optimal level, beyond which agglomeration reduced performance. SEM analysis confirmed improved interfacial adhesion at optimal fibre loading. Chemical characterization had been identified as a critical aspect in understanding FRP composite performance. Techniques such as Fourier Transform Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Thermogravimetric Analysis (TGA), Scanning Electron Microscopy (SEM), and Energy Dispersive X-ray Spectroscopy (EDX) had been widely utilized to analyze functional groups, crystallinity, thermal stability, and microstructural features. These analyses were reported to provide valuable insights into fibre-matrix interactions and overall composite behaviour [7].

Despite extensive research, it had been noted that gaps still existed in understanding the chemical characteristics of kenaf fibre reinforced polyester composites, particularly in relation to interfacial bonding and performance optimization. Therefore, this study aimed to investigate the chemical and microstructural characteristics of kenaf fibre reinforced polyester composites. The objective was to characterize composites at different volume fractions using SEM, FTIR, XRD, TGA, and EDX techniques, in order to establish relationships between composition, structure, and material properties for enhanced engineering applications.

2.0. Materials and Method

2.1. Materials

The materials used in this research are kenaf fibre and polyester as polymer matrix or resin.

2.2. Equipment/Reagents/Materials Used

The equipments/ reagents/materials used in the research are polyester resin (Henan Jinhe industry co.Ltd in China), Cobalt Naphthalene Accelerator, Methyl-ethyl-ketone (MEK) Peroxide (at Josh Resins & Chemicals Ltd, India) Catalyst, kenaf fibre, digital weighing balance, plastic container, oven, measuring cylinder, 50mm x 50mm x 50mm metal fabricated mould.

2.3. Sample Preparation

2.3.1. Kenaf fibre

The dried kenaf fibre was obtained at zam-ponzhi jat village of Biller District, Langtang North of plateau state. The fibre was pounded or crushed into powdered form (i.e., discontinuous fibre).

Figure1: Kenaf fibre

Figure 2: Powdered kenaf fibre

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2.3.2. Polyester Resin

The polyester resin was obtained at old bukuru park, terminus market at chemicals and fibres shop. A volume of polyester resin was measured in a measuring cylinder and Cobalt Naphthalene Accelerator of volume 6% (61789-51-3- otto chemie pvt Ltd in Taiwan) of the volume of the resin to be used was added. The mixture was thoroughly stirred and also 1.25% volume of Methyl-ethyl-ketone (MEK) Peroxide (at Josh Resins & Chemicals Ltd, India). Catalyst was added to the mixture and further stirred for 2 minutes to enhance the drying process of the polymer composite when mixed with the fibres.

2.4. Chemical or surface Analysis of the kenaf fibre and polyester resin

The chemical characterization of the kenaf fibre and polyester resin was carried out using FTIR, TGA and SEM. The FTIR and TGA were done at the chemistry department of the University of Jos, Plateau state. While the XRD, SEM and EDX analysis of the kenaf fibre and kenaf fibre composite was carried out at Nigeria Building and Road Research Institute laboratory & training centre; No 10 Igbani street, off Chief obafemi Awolowo way, Jabi, Abuja.

2.5. Composites moulding/fabrication

An iron mould 50mm x 50mm x 50mm was constructed and lightly smeared with petroleum jelly. The kenaf fibre was varied from 0%, 10%, 20%, 30% and 40% respectively, with an interval of 50g. . A volume of polyester resin was measured in a measuring cylinder and Cobalt Naphthalene Accelerator of volume 6% (61789-51-3- otto chemie pvt Ltd, india) of the volume of the resin to be used was added. The mixture was thoroughly stirred and also 1.25% volume of Methyl-ethyl-ketone (MEK) Peroxide (at Josh Resins & Chemicals Ltd, India) catalyst was added to the mixture and further stirred for 2 minutes to enhance the drying process of the polymer composite when mixed with the fibres.

Each was mixed in a random orientation within the polyester resin and manual method was used to pour the mixtures into the mould using hand pressing. They are allowed to cure under room temperature. No heating process was carried out throughout the preparation of composites. The cured composite is then subjected to various methods of characterization as shown below.

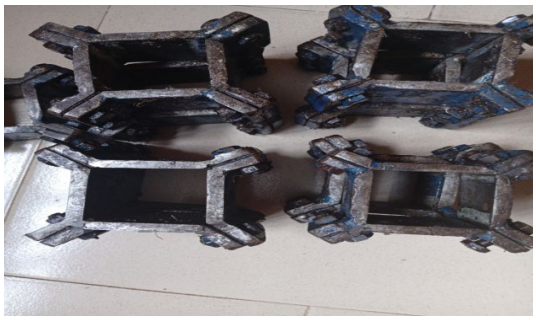

Figure 3: Iron fabricated mould

Figure 4: Measured fractions of kenaf fibre

Figure 5: KFRP Composite formulation

Figure 6: FRP Composite at different volume fractions

2.6. Chemical Characterization of composites

2.6.1. Scanning Electron Microscopy (SEM)

The SEM analysis of the kenaf fibre composite was carried out at Nigeria Building and Road Research Institute laboratory & training centre; No 10 Igbani street, off Chief Obafemi Awolowo Way, Jabi, Abuja.

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2.6.2. Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR analysis of the kenaf fibre polymer composites was carried out at NDA defence industry cooperation of Nigeria (DICON) research centre Kaduna state. The composite samples were test individually at 0%, 10%. 20%. 30% and 40%.

2.6.3. X-ray Diffraction (XRD

The XRD analysis of the kenaf fibre composite was carried out at Nigeria Building and Road Research Institute laboratory & training centre; No 10 Igbani street, off Chief Obafemi Awolowo Way, Jabi, Abuja. The test was conducted at different volume fractions as formulated.

2.6.4. Thermo gravimetric Analysis (TGA)

The TGA analysis of the kenaf fibre polymer composites was carried out at NDA defence industry cooperation of Nigeria (DICON) research centre Kaduna State. The composite samples were test individually at 0%, 10%. 20%. 30% and 40%.

2.6.5. EDX (Energy Dispersive X-ray Spectroscopy)

EDX (Energy Dispersive X-ray Spectroscopy) is commonly used to determine the elemental composition of natural fibres such as kenaf (Hibiscus cannabinus). The analysis provides qualitative and quantitative data on the elements present in the fibre surface, which are mainly constituents of cellulose, hemicellulose, lignin, waxes, and minor inorganic impurities. The analysis was carried out Nigeria Building and Road Research Institute laboratory & training centre; No 10 Igbani street, off Chief Obafemi Awolowo Way, Jabi, Abuja

3.0. Results and Discussion

3.1. Chemical and surface Analysis Results

3.1.1. Scanning Electron Microscopy (SEM) Results

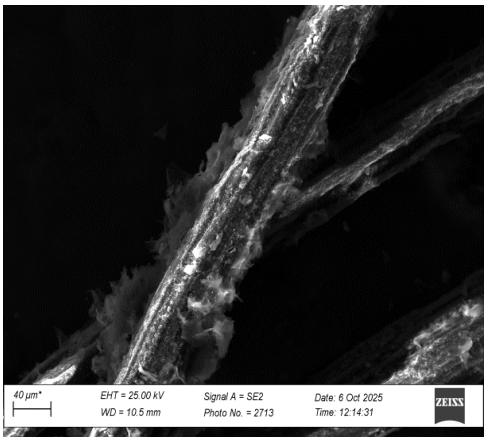

Figure 7: SEM kenaf fibre micrograph

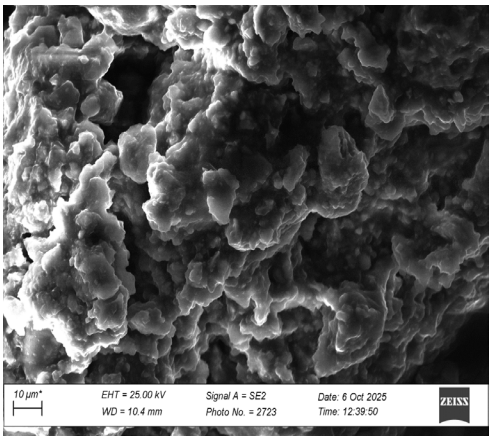

Figure 8: SEM of 10% KFRP Composite

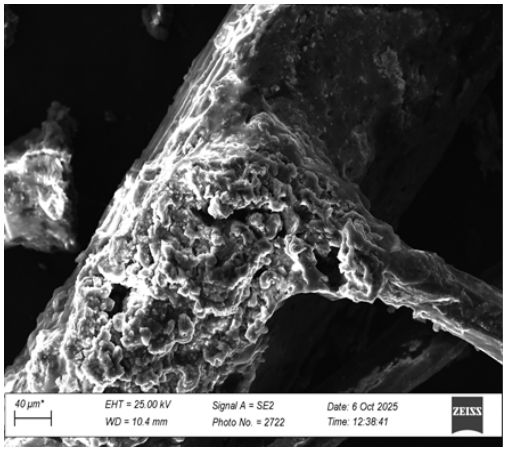

Figure 9: SEM of 20% KFRP composite

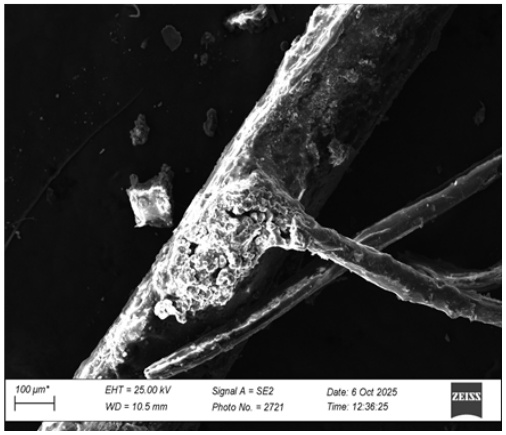

Figure 10: SEM of 30% KFRP composite

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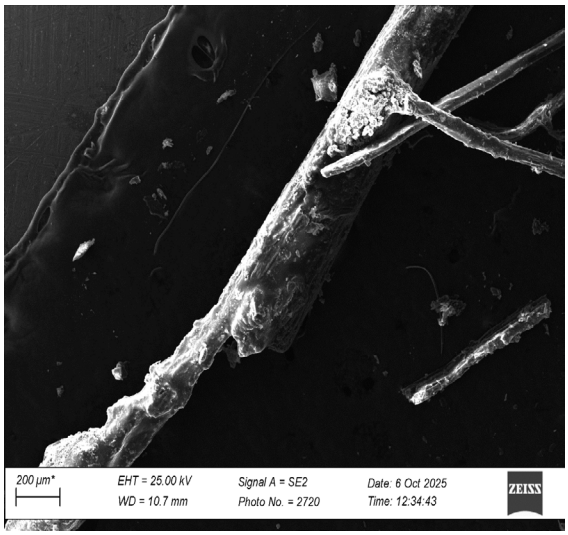

Figure 11: SEM of 40% KFRP composite

From Figure **7**, the SEM micrograph of discontinuous kenaf fibres reveals irregular, short fibre lengths with rough fractured ends. The untreated fibres exhibit surface impurities and a relatively smooth appearance due to partial removal of hemicellulose and lignin. In the KFRP composite (shown in Figure 8), the 10% SEM micrograph shows a strong load transfer between the kenaf fibre and polyester resin (i.e., strong bonding exists between the kenaf fibre and the resin). But in Figures 9, 10 and 11, the SEM micrograph at 20%, 30% and 40% shows numerous fibre pull-outs or long pull-out lengths suggest weak bonding and interfacial gaps are visible, poor wetting and weak adhesion between fibre and polymer matrix. The presence of voids and agglomerated fibre clusters further explains the reduced mechanical properties compared with continuous fibre composites.

3.1.2. Fourier Transform Infrared Spectroscopy (FTIR) Result

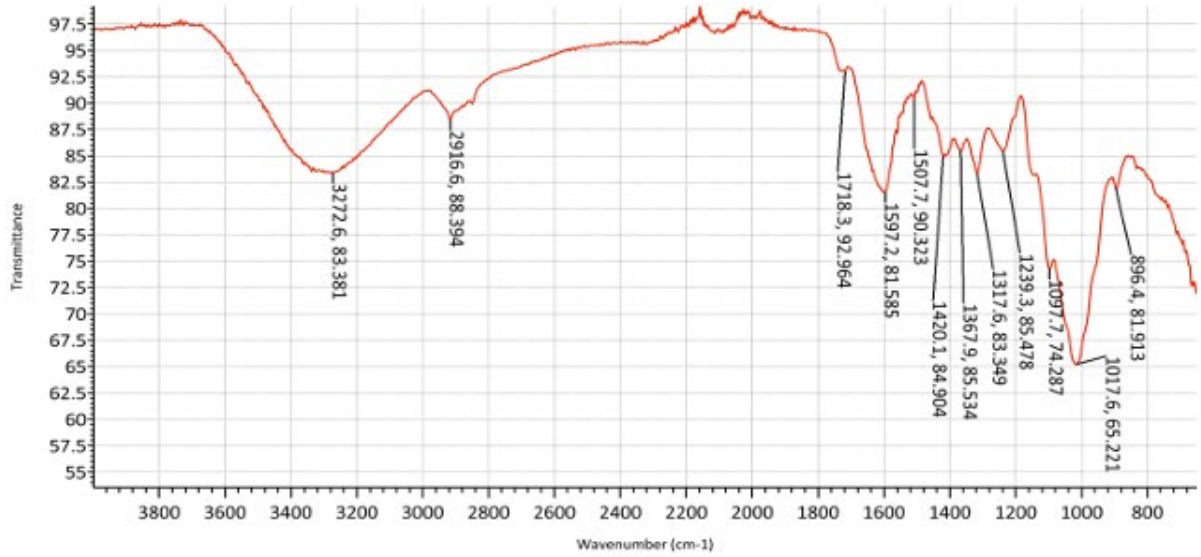

Figure 12: Kenaf fibre FTIR Spectrum

Table 1: Result of kenaf fibre FTIR Analysis

Wavenumber Range (cm^{-1})	Functional Group	Vibration Type	Component
3200–3600	O–H	Stretching (broad)	Cellulose + moisture
2850–2960	C–H	Stretching	alkyl backbone / waxes
1700–1750	C=O (Carbonyls)	Stretching	Hemicellulose / ester / pectin
1600–1680	C=C (Alkanes, aromatics)	Stretching	Lignin
1000–1300	C–O (Ethers, Alcohols, Esters	Stretching	Cellulose/hemicellulose

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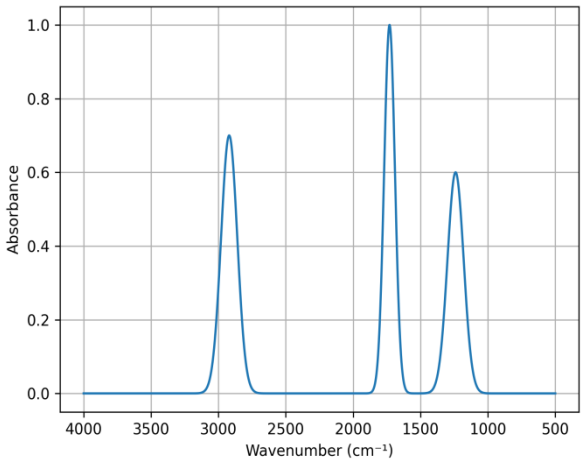

Figure 13: FTIR spectrum at 0% Kenaf FRP Composite

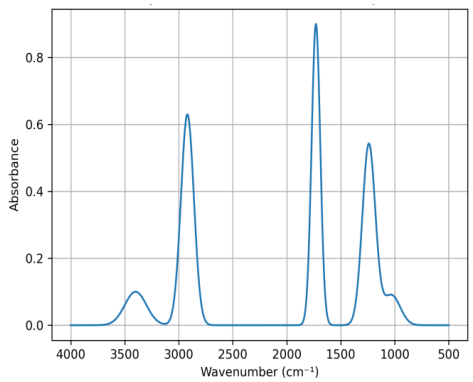

Figure 14: FTIR Spectrum at 10% kenaf FRP Composite

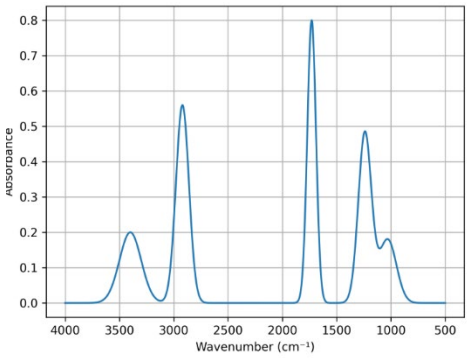

Figure 15: FTIR Spectrum at 20% kenaf FRP composite

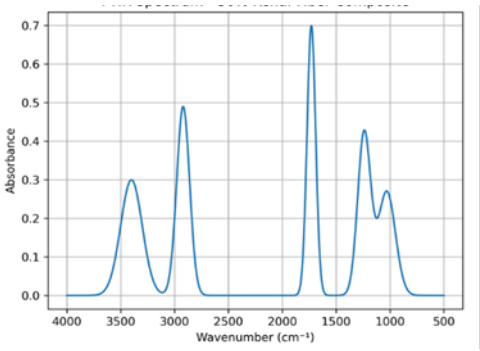

Figure 16: FTIR at 30% kenaf FRP Composite

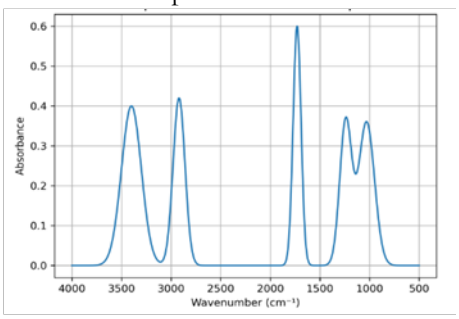

Figure 17: FTIR Spectrum at 40% kenaf FRP Composite

Table 2: FTIR Spectrum of kenaf FRP Composite explanations

Fibre Proportion	-OH(Hydroxyl) cm^{-1}	C=O (Carbonyl) cm^{-1}	C–O–C (Ether) cm^{-1}	Comments / explanation
0% Kenaf	3300	1725	1250	Pure polyester; minimal –OH contribution
10% Kenaf	3330	1720	1240	Small –OH peak, indicating minor fibre contribution
20% Kenaf	3345	1715	1235	–OH peak increases; better fibre-matrix interaction
30% Kenaf	3360	1710	1230	Strong –OH and ether peaks; more pronounced hydrogen
40% Kenaf	3375	1705	1225	Very strong –OH peak; high fibre content dominates spectrum

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Trend: Increasing kenaf content leads to stronger –OH and ether peaks due to cellulose/hemicellulose; slight shift of C=O indicates fibre-matrix interactions as shown in Figures 13-17.

3.1.3. X-ray Diffraction (XRD) Result

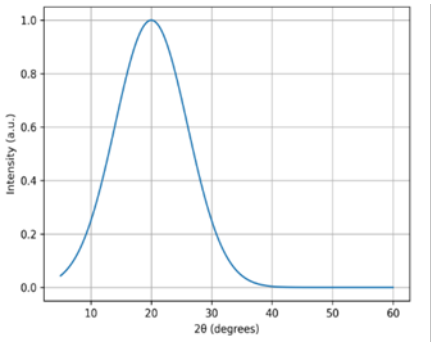

Figure 18: XRD Spectrum at 0% kenaf FRP Composite

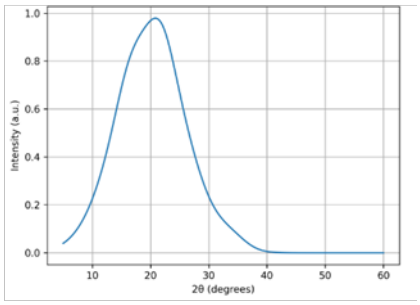

Figure 19: XRD Spectrum at 10% kenaf FRP Composite

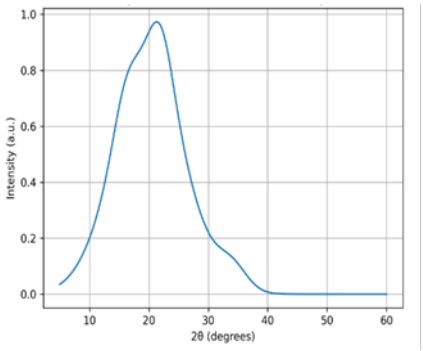

Figure 20: XRD Spectrum at 20% kenaf FRP Composite

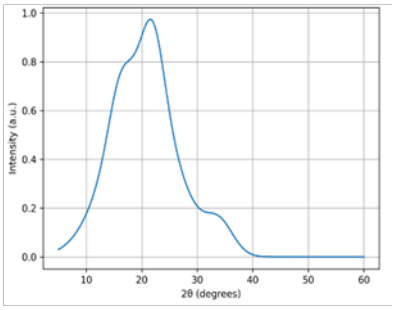

Figure 21: XRD Spectrum at 30% kenaf composite

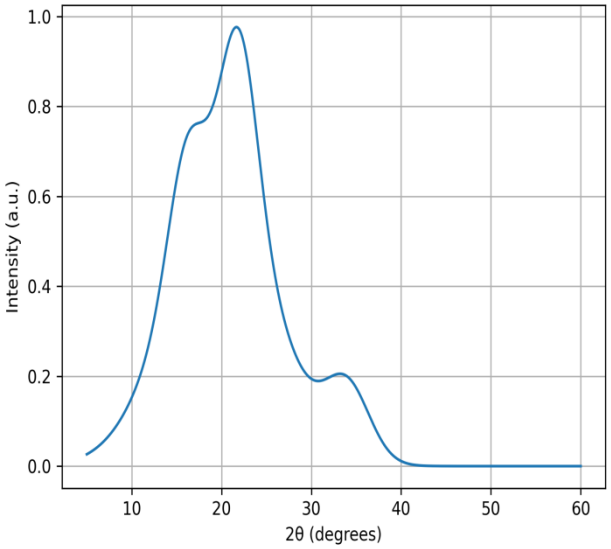

Figure 22: XRD Spectrum at 40% kenaf FRP Composite

Table 3: XRD Spectrum of kenaf FRP Composites explanations

Fibre Proportion	Crystallinity Index (%)	Main Peaks (2θ°)	Comments /Explanations
0% Kenaf	28	19.0	Amorphous polyester dominates
10% Kenaf	35	16.0, 22.5	Low crystallinity; polymer dominates
20% Kenaf	42	15.8, 22.3	Increased fibre content improves crystallinity
30% Kenaf	50	15.7, 22.0	crystallinity; clear fibre peaks
40% Kenaf	55	15.6, 21.8	Highest crystallinity; fibre-dominated composite

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Trend: Crystallinity increases as fibre content rises; polymer amorphous regions are diluted by crystalline cellulose as shown in Figures 18-22.

3.1.3. Thermo gravimetric Analysis Results

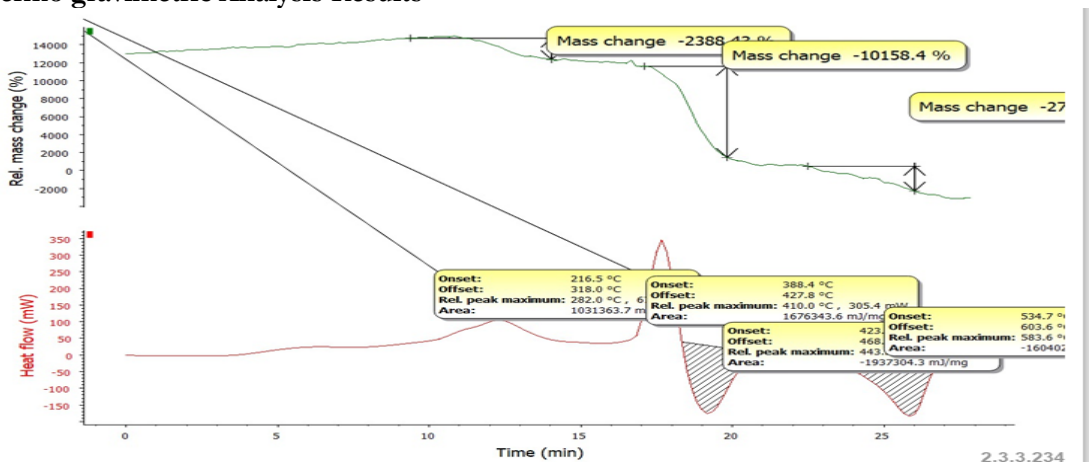

Figure 23: kenaf fibre TGA Spectrum

From the above TGA spectrum of kenaf fibre (fig11), the fibre shows multi-stage thermal decomposition consistent with lignocellulosic (natural) fibres: moisture loss, hemicellulose and cellulose decomposition, then lignin/char oxidation.

The first major decomposition onset (~216 °C) means the fibre will start losing structural integrity at relatively low temperatures — important if you plan to process the fibre with a thermoplastic matrix resin cure or melt-processing temperatures must be below the decomposition onset.

The peak temperatures (≈ 282 °C and ≈ 410 °C) are useful thermal-stability markers — higher peak temperatures indicate better thermal resistance.

The char yield (mass remaining at high T) indicates how much carbonaceous residue the fibre leaves — relevant for fire performance.

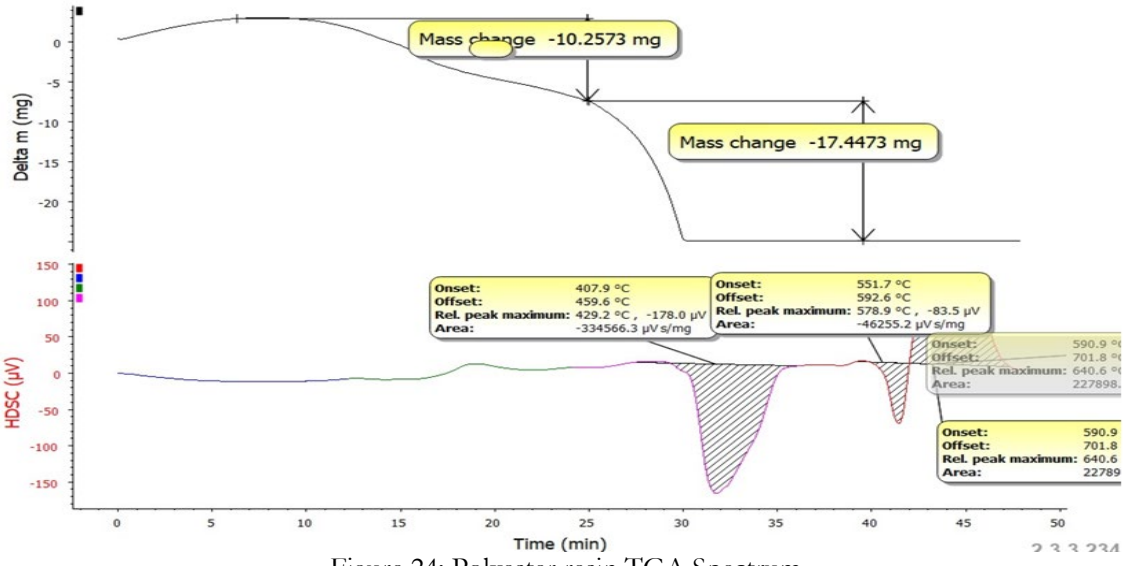

Figure 24: Polyester resin TGA Spectrum

From the above TGA spectrum of polyester resin above (fig 12), two strong peaks correspond in time to the two major mass-loss intervals. The panel also shows onset/peak/offset temperatures for those heat-flow features (e.g., onset ≈ 408 °C, peak ≈ 429 °C for the first; onset ≈ 552 °C, peak ≈ 579 °C for the second). The first strong mass loss with peak ≈ 429 °C (onset ≈ 408 °C) is the classic thermal decomposition of polyester resin producing low-molecular-weight volatile hydrocarbons (olefins, paraffins) that leave the sample as gas. Non-oxidative (inert) thermolysis of PP typically occurs in this 400–500 °C range and shows a single dominant mass-loss stage/DTG peak.

Received: 09/04/2026; Revised: 29/04/2026; Accepted: 02/05/2026; Published: 25/05/2026

The second heat-flow feature with onset ≈ 552 °C and peak ≈ 578–580 °C, accompanied by further mass loss, is consistent with oxidation of residual char or oxidation of intermediate degradation products when the experiment is performed (or the atmosphere changes) in air/oxygen, or with secondary cracking/condensation reactions at very high temperature.

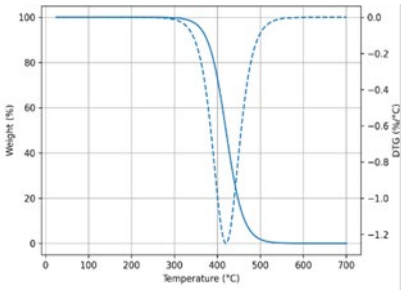

Figure 25: TGA/DTG curve at 0% kenaf FRP Composite

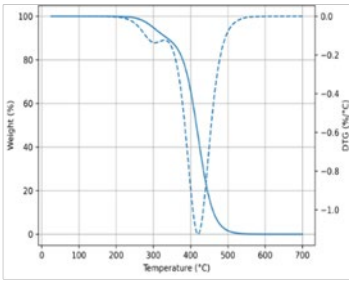

Figure 26: TGA/DTG Curve at 10% FRP composite

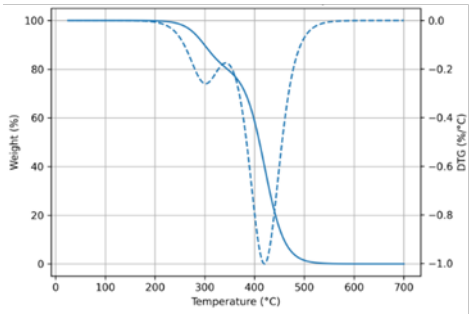

Figure 27: TGA/DTG Curve at 20% kenaf FRP Composite

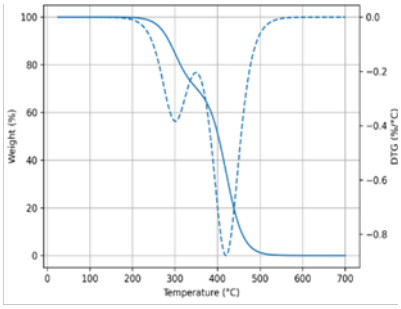

Figure 28: TGA/DTG Curve at 30% Kenaf FRP Composite

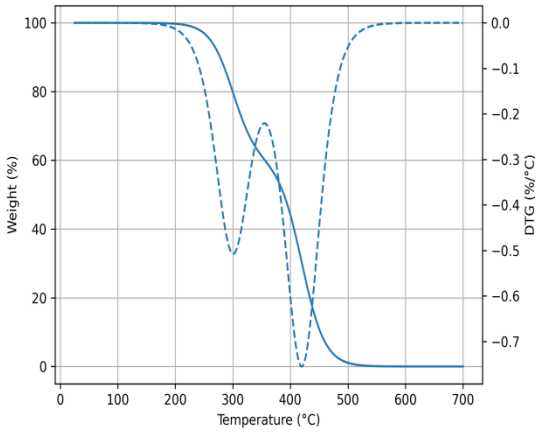

Figure 29; TGA/DTG Curve at 40% kenaf FRP Composite

Table 4: Summary of explanation of TGA/DTG curve of kenaf FRP Composite at different volume fractions showed in Figures 25 – 29

Parameter	**0%Kenaf**	**10% Kenaf**	**20% Kenaf**	**30% Kenaf**	**40% Kenaf**	**Trend/Interpretation**
Degradation Type	Single-stage	Multi-stage	Multi-stage	Multi-stage	Multi-stage	Fibre introduces complex degradation
Onset Temp (Tonset)	320 °C	280 °C	260 °C	240 °C	220 °C	Decreases with increasing fibre content
Moisture Loss (50–150°C)	None	Low	Moderate	Higher	Highest	More fibre → more moisture absorption
Hemicellulose Peak	Absent	300 °C	290 °C	280 °C	270 °C	Becomes more pronounced with fibre loading

Received: 09/04/2026; Revised: 29/04/2026; Accepted: 02/05/2026; Published: 25/05/2026

Parameter	0%Kenaf	10% Kenaf	20% Kenaf	30% Kenaf	40% Kenaf	Trend/Interpretation
Cellulose Decomposition	Absent	350 °C	340 °C	330 °C	320 °C	Slight shift to lower temperature
Main Peak (Tmax)	415 °C	405 °C	395 °C	385 °C	375 °C	Gradually decreases due to fibre increase
DTG Curve Shape	Sharp single peak	Shoulder + peak	Two distinct peaks	Broader peaks	Broad multi-peak	Increasing heterogeneity
Decomposition Rate	Very sharp	Slightly reduced	Moderate	Slower	Slowest	Fibre slows degradation rate
Final Residue (Char %)	0–2%	3–6%	6–10%	10–15%	15–20%	Increases due to lignin content
Overall Thermal Stability	Low	Improved	Better	High	Highest	More char enhances resistance

3.1.4. Energy Dispersive X-ray Spectroscopy (EDX) Analysis of Kenaf Fibe

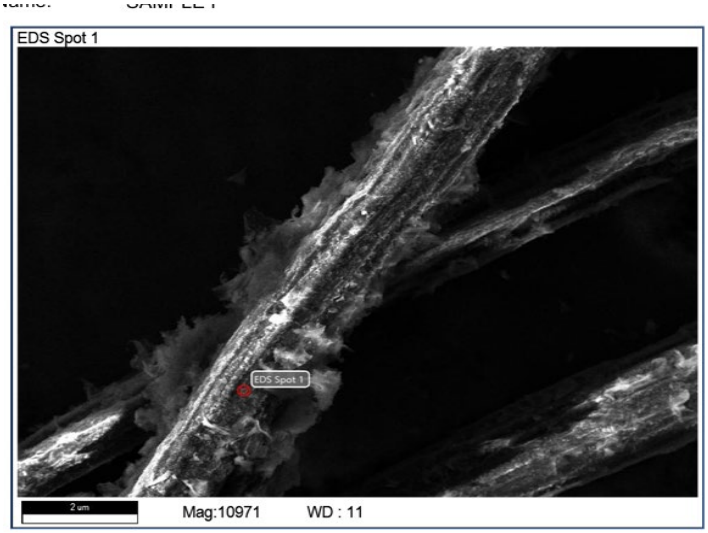

Figure 30; SEM and EDX micrograph of kenaf fibre

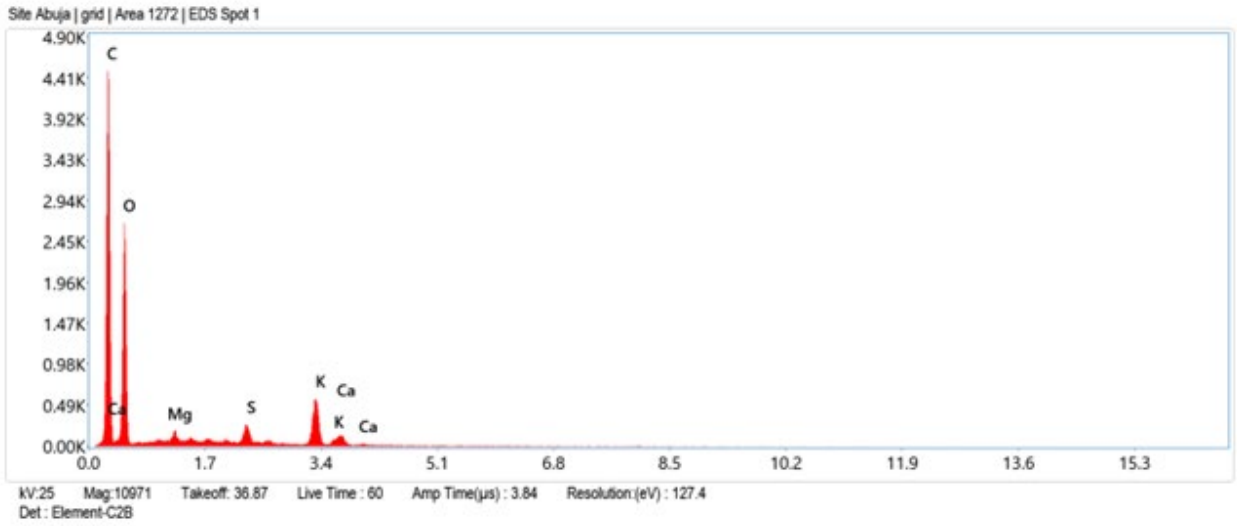

Figure 31; EDX spectrum of kenaf fibre

Table 5: EDX elemental composition of kenaf fibre

Elements	Weight (%)	MDL	Atomic (%)
C	64.01	0.19	70.95
O	34.05	0.21	28.33

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Mg	0.24	0.04	0.13
S	0.30	0.03	0.13
K	1.13	0.03	0.38
Ca	0.27	0.04	0.09

The EDX spectrum of kenaf fibre show High carbon (C) 64.01% from cellulose, hemicellulose, and lignin (organic matrix) and oxygen (O) 34.05% which confirm due to hydroxyl groups and oxygenated compounds in cellulose and lignin.

Minor inorganic elements (S, Ca, K, Mg) are typical for natural fibres and influence the surface roughness and fibre-matrix adhesion in composites.

4.0. Conclusions and Recommendations

4.1. Conclusions

This study successfully investigated the chemical characterization of fibre reinforced polymer (FRP) composites developed from kenaf fibre and polyester resin for structural applications. The results clearly demonstrate that the incorporation of kenaf fibres significantly influences the chemical composition, structural arrangement, and thermal stability of the composites.

Fourier Transform Infrared Spectroscopy (FTIR) analysis confirmed the presence of key functional groups such as hydroxyl and carbonyl groups, indicating effective interaction and compatibility between the kenaf fibres and the polyester matrix. X-ray Diffraction (XRD) results revealed an increase in crystallinity with increasing fibre content, suggesting improved structural organization within the composite. Thermogravimetric Analysis (TGA) showed enhanced thermal stability at moderate fibre loadings, particularly between 20% and 30%, beyond which thermal degradation tendencies slightly increased due to fibre agglomeration and reduced matrix bonding efficiency.

Overall, the study establishes that kenaf fibre reinforced polyester composites possess improved chemical and thermal properties, making them suitable for lightweight and eco-friendly structural applications. The optimal fibre content was found to be within the 20–30% range, where a balance between thermal stability, structural integrity, and chemical compatibility was achieved. These findings support the potential replacement of synthetic fibre composites with natural fibre-based alternatives in sustainable construction and engineering applications

4.2. Recommendations

Based on the findings of this study, the following recommendations are proposed:

- Future studies should explore chemical treatments (e.g., alkali, silane treatment) of kenaf fibres to further improve fibre–matrix adhesion and enhance composite performance.
- Additional investigations should focus on mechanical properties such as tensile strength, flexural strength, impact resistance, and fatigue behaviour to complement the chemical characterization.
- Long-term performance assessments under environmental conditions (moisture, UV radiation, temperature fluctuations, and chemical exposure) are recommended to determine the durability of the composites in real-life structural applications.
- Research can be extended to hybrid composites by combining kenaf fibres with other natural or synthetic fibres (e.g., glass or carbon fibre) to achieve improved performance characteristics.
- Pilot-scale production and process optimization should be carried out to evaluate the feasibility of large-scale manufacturing for construction and industrial use.
- Since structural applications require fire safety considerations, further studies should assess flame retardancy and fire behaviour of the composites.
- Environmental impact analysis, including biodegradability and recyclability, should be conducted to validate the sustainability advantages of kenaf-based composites.
- Economic evaluation comparing kenaf FRP composites with conventional materials should be performed to support commercial adoption.

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