Pertanika J. Sci. & Technol. 31 (S1): 39 - 57 (2023)

PERTANIKA JOURNALS

SCIENCE & TECHNOLOGY

Journal homepage: http://www.pertanika.upm.edu.my/

Improved Thermal and Mechanical Properties of Kenaf Fiber/ ABS Polymer Composites via Resin Coating Treatment

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ABSTRACT

In developing natural fiber composites (biocomposites), compatibility between natural cellulosic fibers and polymers has always created serious challenges, reducing performance. This study focused on applying a novel approach using epoxy resin as a coating medium to enhance the properties of the fibers and the interface between the hydrophobic polymer and the hydrophilic natural fiber. 10 wt% of uncoated kenaf fibers (KF) and coated kenaf (CKF) fibers were compounded with acrylonitrile butadiene styrene (ABS) thermoplastic polymer in a twin-screw extruder at an optimized temperature of 220°C under the same processing conditions. Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM) examined the coated and uncoated fibers' physicochemical compositions and

ARTICLE INFO

Article history:
Received: 06 March 2023
Accepted: 24 July 2023
Published: 27 October 2023

DOI: https://doi.org/10.47836/pjst.31.S1.03

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ISSN: 0128-7680
e-ISSN: 2231-8526

surface properties. The developed composites' thermal, mechanical, and microstructural characteristics were also examined, and the results revealed that the CKF/ABS composites had better interfacial bonding and mechanical characteristics than the uncoated KF/ABS composite. Coating natural fibers with epoxy resin is a novel technique for improving interfaces and developing environmentally friendly composites from natural sources.

Keywords: ABS composites, kenaf fibers, mechanical properties, resin coating, thermal degradation and stability

INTRODUCTION

Natural fibers are environmentally friendly because of their biodegradability and great intrinsic properties, making them suitable with great potential for various industrial applications (Achukwu et al., 2022; Akil et al., 2011; Doumbia et al., 2015; EI-Abbassi et al., 2019; Sapuan et al., 2013; Reddy et al., 2021). They are usually obtained from animals, minerals, or plants and include but are not limited to coir, silk, wool, kenaf, cotton, sisal, hemp, jute, bagasse, flax, and bamboo fibers (Gourier et al., 2017; Uzochukwu et al., 2020; Achukwu, Barnabas, et al., 2015). Thus, more research efforts are being made to replace synthetic fibers with natural fibers to make polymer composites that are environmentally friendly and affordable (Odesanya et al., 2021). Several industries and researchers are turning to lignocellulosic fibers from biomass waste to replace synthetic fibers and reinforced bio-based polymer composites. Due to their biodegradability, low carbon emissions, and accessibility, green composites are becoming more prevalent in the composites industry (Asyraf et al., 2023). Various green composites with good mechanical strength have been produced employing a variety of natural fibers and biodegradable polymer matrices (Asyraf et al., 2022; Ku et al., 2011; Ramesh et al., 2017).

These natural fibers, particularly jute and kenaf fibers from bast origins, are currently being utilized as reinforcement materials in high-temperature engineering thermoplastic composites with applications in the aviation and automotive sectors (Owen, Achukwu, Romli, & Akil, 2023). Natural fiber composites, including kenaf ones, have recently become popular because of their outstanding mechanical qualities. Compared to other natural fibers, kenaf fiber offers many advantages in strength and stiffness (Nurazzi et al., 2021). Due to the significant improvement in mechanical performance, researchers prefer to incorporate kenaf fibers with a polymer matrix (Radzuan et al., 2019). Furthermore, it benefits from reduced harmful fume emissions during production when heated. Therefore, hydrophilic natural fibers are poorly compatible with hydrophobic polymer matrixes. Due to this incompatibility, it is difficult to achieve effective fiber-matrix interface bonding, which results in poor load transfer between the matrices and reinforcing material (Asumani et al., 2012; Norrrahim et al., 2021). This flaw could degrade the composites' mechanical properties and prevent using natural fiber-based composites in load-bearing applications (Achukwu et al., 2023; Feng et al., 2020).

ABS polymer is a high-temperature plastic often processed at around 200–260°C, significantly impacting the finished products' performance. Reports on the thermo-physical characteristics of ABS kenaf composites have been presented in some studies. For instance, a study on the thermo-physical characteristics of kenaf-filled acrylonitrile butadiene styrene (ABS) composites was published by Nikmatin et al. (2017). They looked at the impact of kenaf short fiber and kenaf microparticle size on kenaf-ABS composites. According to their findings, the composite made of kenaf short fiber and ABS has the highest level of crystallinity. However, due to double bonds in the constituent polybutadiene, ABS is occasionally vulnerable to breakdown at high processing temperatures. To overcome this, ABS is frequently combined with various natural polymers that can lessen the impact of the processing temperature (Owen, Achukwu, Arukalam, & Romli, 2022).

When likened to other natural fibers, kenaf fibers have shown superior mechanical properties with applications in non-woven, molded, and extruded products, but the major challenge to their utilization is their incompatibility with hydrophobic polymers and degradation at high processing temperatures. These negatively affect their thermal and mechanical properties. Attempts have been made to address these challenges with varying degrees of success. Reported treatments such as alkalization and silanization have been valuable in solving some of the problems (Achukwu, Dauda, et al., 2015; Achukwu, Ochika et al., 2015; Kabir et al., 2012; Oushabi et al., 2017). Nevertheless, issues regarding degradations at increased processing temperatures have not yet been addressed, particularly with engineering thermoplastics like polybutylene terephthalate (PBT), acrylonitrile butadiene styrene (ABS), and polyethylene terephthalate (PET) (Mohammed et al., 2015; Owen, Achukwu, Akil, et al., 2022). Initial studies on natural fiber-reinforced recycled and virgin polyethylene terephthalate using the resin surface coating treatment revealed remarkable success in enhancing the thermal stabilities and interfacial contact of natural fibers with high-temperature thermoplastics (Owen, Achukwu, Hazizan, et al., 2022; Owen et al., 2018a).

The new surface coating technique was also used to improve the impact properties and thermal stability of leather fiber-filled ABS composites (Owen, Achukwu, Arukalam, Talib, & Romli, 2021; Owen, Achukwu, Arukalam, Muhammad, & Romli, 2021) at 240°C processing temperature. The finding presented the highest impact strength for the coated composite with a value of 0.126 KN/mm^2 at 5 wt% filler loading and more thermal stability than uncoated. It enhanced the processability of natural fibers at high temperatures (improvements in thermal stability), leading to the development of high-strength composites for engineering applications. Owen, Achukwu, Akil, et al. (2022) reported the effect of varying processing temperatures (200, 220, and 240°C) with constant fiber loading, using epoxy resin/hardener and an acetone ratio of 1:5 for coating the kenaf fibers. The tensile and flexural strengths of the epoxy-coated kenaf/ABS composite did not vary much as a

result of the processing temperatures; however, the composites' fatigue behaviors were significantly affected.

The present study presents the improvement in thermal and mechanical properties of resin-coated kenaf fibers in engineering ABS thermoplastic polymer at a single optimized processing temperature of 220°C, using an epoxy/hardener and acetone ratio of 1 (epoxy):4 (acetone) for coating, and the development of cheaper and greener kenaf fiber/ABS composites suitable for high-temperature engineering and load-bearing applications.

EXPERIMENTAL

Materials

Commercial-grade ABS polymer pellets with a density and melt flow index (MFI) of 1.05 g/cm^3 and 8.6 g/10 min, respectively, were provided by Toray Plastics Malaysia Sdn. Bhd., Prai and were employed as the binder. Raw kenaf fibers (KF) shown in Figure 1(b) were provided by the Malaysian Agricultural Research and Development Institute (MARDI), Malaysia. The coating medium (epoxy resin/hardener) and acetone (C_3H_6O) of analytical grade were supplied by Oriental Option Sdn. Bhd., Bayan Lepas, Penang and SYSTERM, Syah Alam, Selangor.

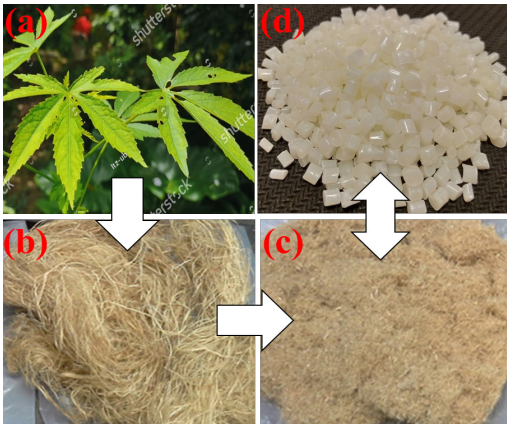

Figure 1. Visual representations of (a) kenaf plant, (b) kenaf fibers, (c) pulverized resin-coated kenaf fiber (5 mm size), and ABS polymer chips

Kenaf Fiber Processing and Resin Surface Coating Treatments

After being dried for 48 hours at 24 ± 1.5°C and 76 ± 1% relative humidity, the provided KF were ground into short fibers (5 mm) (Figure 1c) using the pulverizing apparatus (Fritsch Power Cutting Mill Pulverisette 15, Germany). The fibers were subjected to 6% NaOH for 3 hours to improve ABS compatibility, thermal resistance, and wettability and reduce moisture absorption tendencies of the kenaf fibers. The kenaf fibers were then neutralized with 1% acetic acid before being rinsed with distilled water to maintain a pH of 7. The fibers were dried in an oven for 12 hours at 70°C before being surface coated with epoxy resin made from a 2:1 mixture of epoxy resin and hardener. The resultant mixture was dissolved in acetone at a predetermined optimum ratio of 1 (epoxy):4 (acetone) (Owen et al., 2022c). The coated kenaf fibers were cured for 24 hours at 80°C.

Composites Preparation

At an ideal screw speed and processing temperature of 50 r/min and 220°C, respectively, acrylonitrile butadiene styrene (ABS) was compounded with 10 wt% kenaf fiber and melt-mixed using a twin-screw extruder (model PRISM TSE SYSTEMS 2094, UK). Before being compress-molded into composite sheets for 5 minutes at a continuous compression molding pressure of 65 kg/m^2, the extrudates were ground and dried at 80°C for 3 hours. The times for preheating, hot pressing, and cold pressing (cooled at 25°C) were 2, 3, and 5 minutes, respectively, before the final composite characterization.

Fiber and Composites Characterization

Tensile Testing of Kenaf Fibers. Before the development of the composite, a tensile test was performed on the uncoated kenaf fiber and the kenaf fiber coated with resin. An INSTRON (Shimadzu, Japan) equipped with a suitable load cell type 2511-317 with a maximum load of 10-500 kg was employed to assess the tensile properties (strength and elongation) of the kenaf fibers at a humidity and temperature of 65 ± 2% RH and 20 ± 2°C, respectively. Ten samples were randomly selected from the bale of kenaf fibers according to their maturity, fineness, and length. The linear density in tex was measured, and the fibers were subjected to a tensile strength test using a gauge length of 10 mm following the ASTM D3379 single fiber tensile test standard at a speed of 1 mm/min. Tests were conducted at a standard laboratory atmosphere of 23°C and 50% relative humidity. Ten specimens were tested, and the average value was reported.

Analysis of Kenaf Fibers Using Scanning Electron Microscopy. An SEM micrograph of the fiber surface was taken using a Hitachi Scanning Electron Microscope model (TM 3030 PLUS Japan) at a magnification of 500x and an accelerating voltage of 5–20 kV to investigate the impact of epoxy coating on morphological alterations of kenaf fibers.

Analysis of Kenaf Fibers Using Fourier Transform Infrared Spectroscopy. To look at changes in chemical structures and functional groups, FTIR spectroscopic analysis of both uncoated (KF) and resin-coated kenaf fibers (CKF) was performed using an FTIR spectrometer (Perkin Elmer Spectrum 400, USA). The samples' spectra between 4000 cm^{-1} and 400 cm^{-1} were examined.

Analysis of Kenaf Fibers Using Thermogravimetry. Before inclusion into ABS, thermogravimetric analysis (TGA) was used to evaluate the heat resistance and breakdown temperature of the resin-coated kenaf (CKF) with the uncoated fiber samples. Thermogravimetric analyzer type NETZSCH TG 209 F3 Tarsus Instrument, Germany, was used for this, and test procedures were carried out in line with ASTM D3850 Standards.

In a nitrogen gas environment, the temperature varied from 30 to 600°C at a heating rate of 10°C/min.

Mechanical Testing of the Kenaf Composites. According to ASTM D790 (2017) and ASTM D638-03 (2012), respectively, three-point flexural and tensile tests were performed using a SHIMADZU Autograph Precision Universal Tester (Model AG-X Series, Japan) in a typical laboratory environment of 50% relative humidity and 23°C. Five specimens that were accurately sized and cut out using a band saw were examined for tensile and flexural properties at crosshead speeds of 5 and 2 mm/min, respectively. Additionally, based on ISO 179-1 (2010) standards testing procedures, impact strength was tested using an impact machine of the INSTRON dynatup (model 9250HV USA) design. The strength of composite samples under sudden load applications was tested using this method. Each test employed five replicate specimens, and the findings shown are the average results of tests run on all the composite samples.

Analysis of Kenaf-ABS Composites Using Scanning Electron Microscopy. The microstructural characteristics of kenaf-ABS composites were examined using the SUPRA 40VP Model of the Field Emission Scanning Electron Microscope (ZEISS FE-SEM Germany). To prevent the weak resolution from electrostatic charge and increase the surface conductivity, a thin layer of platinum was sputter coated onto the broken surfaces of the tensile samples using a Quorum Sputter-Coater device (Quorum model Q150RS, UK). The photographs were taken at a 500x resolution with the samples angled at 30° for easier observation.

On an optical microscope (Olympus BX51TRF model, Japan) equipped with an optic camera, the optical pictures of ABS, uncoated kenaf (KF), and coated kenaf fibers (CKF) distributions in the ABS matrix composite system were studied at 10x and 20x magnifications.

RESULTS AND DISCUSSION

FTIR Analysis

The combined FTIR spectra for resin-coated-treated (CKF) and kenaf fiber (KF) are displayed in Figure 2.

The vibration peak intensities of kenaf fibers (KF) were found at 1028–1750 cm^{-1}, which revealed the presence of lignin, cellulose, and hemicelluloses with their broad bands, which was also mentioned by Asim et al. (2016). The CH_2 groups in hemicelluloses and cellulose's C-H stretching vibration are responsible for the absorption peaks at 2910 cm^{-1}. The hydroxyl-OH group can also be found at 3336 cm^{-1} in the kenaf fiber. The spectrum of surface-coated kenaf fiber (CKF) in Figure 2 shows a significant reduction in peak

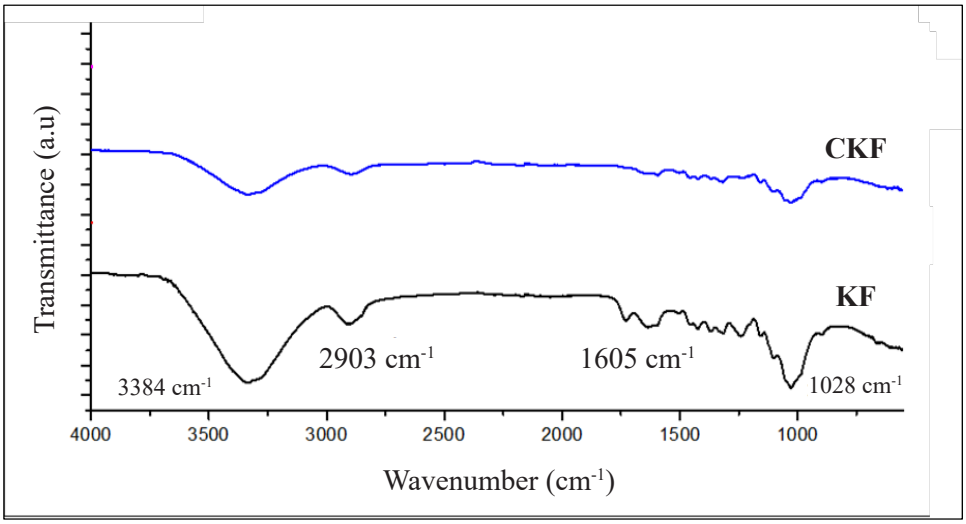

Figure 2. The combined spectra of resin coated kenaf (CKF) and raw kenaf (KF)

intensities, an indication of improved fiber surface concerning kenaf fibers as a result of resin coating treatment. The result means that the surface resin coating treatment has reduced the fiber's hydrophilicity and water intake characteristics without adversely altering the fiber's chemical content. The C=C stretch absorption band of the ester carbonyl group occurred at 1730 cm^{-1}, showing that an ester chain was formed between the hydroxyl group contained in the fiber and the epoxy resin-coated fiber (Razak et al., 2014). The fiber's epoxy resin and cellulosic hydroxyl group interacted well, leading to the missing peaks at 1730 cm^{-1} and 2910 cm^{-1}. Asim et al. (2016) also reported the presence of a vibrational peak between 3336 cm^{-1} and 3400 cm^{-1}, indicating a frequency due to the O-H group.

The aldehyde in lignin and the acetyl ester in hemicelluloses peaked at 1730 cm^{-1}. It was also observed that the spectra of resin-coated kenaf fibers (CKF), which revealed low peak intensity and its effect on lignin and hemicelluloses, are indications of successful coating treatment. Removing lignin, hemicelluloses, and wax effectively broadens the absorption peak at 3336 cm^{-1} relative to the untreated fiber. A large amount of the hydroxyl groups found in the kenaf fiber have been coated by the epoxy resin, which also served as a coupling agent in reducing the moisture absorption characteristics of the kenaf fibers after coating treatment. A similar observation on reduction in the hydroxyl group was reported by Tan et al. (2011) when empty fruit fibers were treated with maleic anhydride, which led to the formation of cross-linked networks.

Tensile Properties of Kenaf Fibers

From the results obtained in Table 1, it was observed that the coating has a significant effect on the tensile properties of kenaf fibers; the breaking load of kenaf fibers increased after coating, and the highest breaking load (29.78 N) was obtained compared to 27.63 N for the raw kenaf fibers at the same gauge length and fiber count.

Table 1

Tensile properties of uncoated and resin-coated kenaf fibers

Sample	Sample Description	Gauge length (mm)	Breaking Force (N)	Tenacity (N/tex)	Elongation (%)	Count (Ne)
Kenaf (KF)	Uncoated kenaf fibers	10	27.63 ± 0.6	71.58 ± 3	7.78 ± 0.2	38.6 ± 0.1
Coted kenaf (CKF)	Resin-coated kenaf fibers	10	29.78 ± 0.3	99.93 ± 5	6.64 ± 0.3	38.6 ± 0.2

Similar behavior can be said for the strength at break (tenacity), which increased to 99.93 N/tex from 71.58 N/tex with decreased elongation at break (7.78 to 6.64%). The decrease in elongation at break can be attributed to the coated surface losing its elasticity due to the encapsulation effect because bast kenaf fibers are long-staple natural fibers that contain numerous element fibers as well as a matrix of lignin and hemicelluloses in each fiber bundle (Asim et al., 2016).

Morphological Analysis of Kenaf Fibers by SEM

The micrographs of resin-coated kenaf fibers (CKF) and kenaf fibers (KF) are shown in Figures 3a and 3b, respectively.

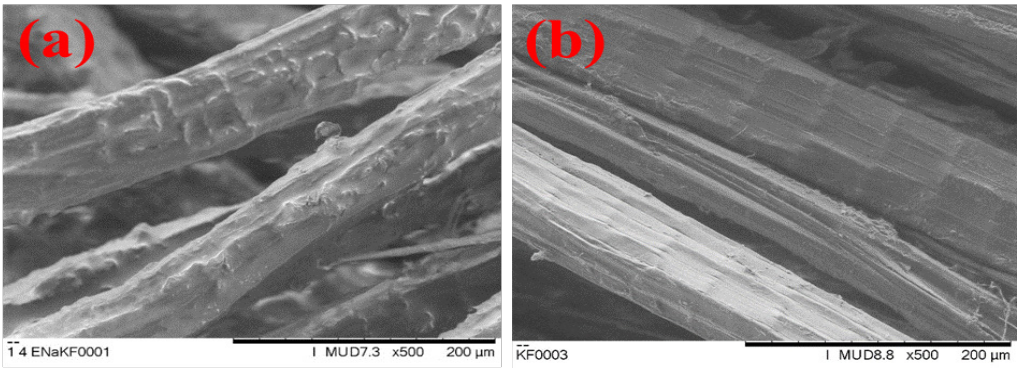

Figure 3. Morphology of (a) resin-coated kenaf fiber (CKF) and (b) kenaf fibers (KF)

It is detected that the resin-treated and coated kenaf fibers, CKF (Figure 3a), revealed some structural changes and a cleaned surface void of impurities as compared to the kenaf fibers due to surface coating treatment, which indicates that the initial fiber surface treatment with NaOH before resin coating treatment removed the surface lignin, hemicelluloses, and pectin substances resulting in rough topography, as also mentioned by Tan et al. (2011). The epoxy-coated kenaf fibers (CKF) also showed smooth surfaces, which confirmed the presence of a coating on the kenaf fibers (Figure 3a). As expected, enhancement in aspect ratio and rough surface topography development is very important in improving the fiber-matrix interface and their adhesion; the mechanical properties will also improve. The epoxy resin has also covered the porous structures on the fibers, providing good mechanical interlocking with the ABS matrix chain, hence developing strong fiber-matrix bonding, as seen in FESEM micrographs. According to Figure 3b's SEM study of raw, untreated kenaf fibers, the surface view of raw kenaf fibers showed the appearance of impurities on the samples, which could account for the weak connection between the fiber and matrix contact. As previously observed, it may cause the composites' poor mechanical properties (Owen, Achukwu et al., 2018).

Thermal Analysis of Resin-coated Kenaf and Uncoated Kenaf Fibers

Figure 4 displays the samples' TGA thermograms, while Table 2 shows the thermal degradation and stability results of uncoated kenaf fibers (KF) and resin-coated kenaf fibers (CKF).

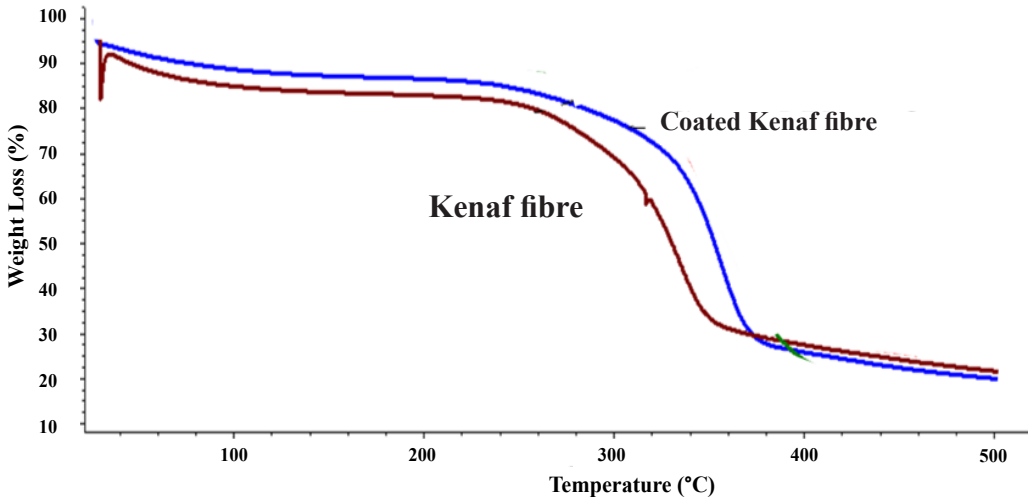

Figure 4. TGA Thermograms of resin-coated kenaf fiber (CKF) and uncoated kenaf fiber (KF)

KF was found to have lower thermal stability, with degradation beginning at around 297.7°C, which is attributed to the breakdown of cellulosic materials like hemicellulose and cellulose and a decomposition temperature of 334.6°C because of the breakdown of noncellulosic components in the fibers (Dehghani et al., 2013). At the same time, CKF's decomposition and beginning of degradation temperatures were stable over 300°C and showed improved thermal stability with peak and onset temperatures of 381.7°C and 331.6°C, respectively, compared to uncoated kenaf fibers (KF), with a minimum mass residual of 10.65%.

When compared to uncoated KF samples, CKF demonstrated a significant improvement in thermal stability. The thermal results are consistent with those from Thitithanasarn et al. (2013), who discovered that the improved contact between the jute fibers and the resins caused the thermoset resin-coated fabrics to break at a greater temperature than the uncoated jute, and it was found that the thermoset resins-coated jute fabric decomposed at a higher temperature than the uncoated jute. The TGA data in Figure 4 show that epoxy coating improved the kenaf fiber's thermal stability without changing the fiber's composition (Dehghani et al., 2013). The onset and peak temperatures of the natural, uncoated kenaf fibers, KF, were 297.7°C and 351.9°C, respectively, with a substantial mass residual value of 18.15%. It suggests CKF is more thermally stable than untreated, kenaf fiber. These outcomes are closely correlated with the composite materials' mechanical characteristics, where the mechanical properties of CKF/ABS composites were superior to the uncoated KF/ABS composites (Figures 5 and 6) at high temperatures (220°C) without fiber degradation. The thermal data obtained have demonstrated that treating the fiber with epoxy resin for a surface resin coating can improve the kenaf fibers' resistance to heat deterioration.

Table 2
Thermal decomposition characteristics thermogravimetric analysis (TGA) of uncoated KF and resin-coated kenaf fiber CKF

Sample codes	Description	Onset degradation temperature (°C)	DTG Peak (°C)	Mass Residual (%)
KF	Kenaf fiber	297.7	351.9	18.15
CKF	Resin coated kenaf	331.6	381.7	10.65

Mechanical Properties

Tensile Properties. The effects of resin coating treatment on the tensile parameters (strength and modulus) of ABS composites filled with kenaf fiber are depicted in Figure 5 for comparison. It can be observed that there are some degrees of improvement in the tensile strength of the coated kenaf/ABS composites compared to the uncoated kenaf-reinforced ABS and KF/ABS composites. The tensile strengths of CKF/ABS composites with epoxy

coating, uncoated KF/ABS, and unfilled ABS were 42.4 MPa, 37.46 MPa, and 39.2 MPa, respectively. The observations are that the strength values of neat ABS dropped slightly upon incorporating the fillers. The tensile strength of CKF/ABS composites was superior as compared to KF/ABS, with about 4.6% improvement, demonstrating a strong interfacial connection between the ABS polymer matrix and the resin-coated kenaf fibers (CKF) as a result of the epoxy coating's impact on increasing tensile strength. Uncoated kenaf KF/ABS composites were discovered to have the lowest modulus (2407.10 MPa), while CKF/ABS composites likewise displayed the highest tensile modulus of 2553.21 MPa.

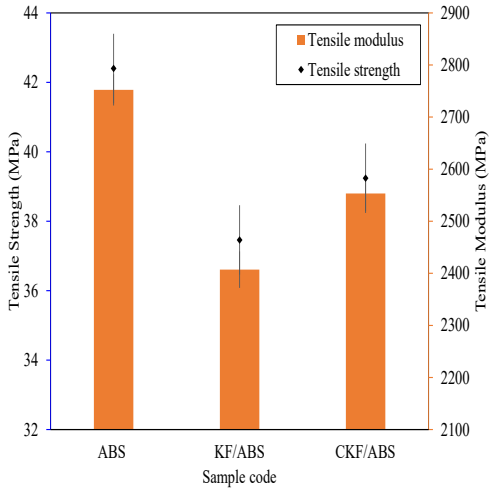

Figure 5. Tensile strength and modulus of resin-coated kenaf fiber (CKF) and uncoated kenaf fiber (KF)

According to the results, resin coating treatment improves the tensile characteristics of ABS composites filled with kenaf fiber, and in comparison to the uncoated composite, epoxy-coated composites produced better tensile characteristics. Due to the jute fabric's higher stiffness following epoxy coating treatment, Thitithanasarn et al. (2012) also noted increased tensile characteristics when applying a similar treatment.

Flexural Properties. Figure 6 shows the flexural strength and modulus of kenaf fiber-filled ABS composites. It can be observed that the coating treatment also improved the resistance to bending for the resultant composites; hence, the flexural strength values of the CKF/ABS composite were 61.09 MPa, which is higher compared to those of the uncoated kenaf (KF/ABS) composite with strength values of 58.21 MPa. The low flexural strength value of the KF/ABS composite could be a result of fiber degradation and low strength caused by poor interfacial adhesion or weak interfaces between raw kenaf and the ABS matrix, which is an incompatibility between the hydrophilic kenaf fibers and the hydrophobic ABS polymer while the KF/ABS composites were typically lower than the CKF/ABS composites, which have an outstanding improvement of 4.7%, and shown the potential that the composite strength could increase with a higher percentage of fiber loading as the modulus of CKF/ABS was higher compared to KF/ABS.

The maximum flexural modulus for the CKF/ABS composites was discovered to be 2400.5 MPa, which is the composites' stiffness and resistance to bending. Due to fiber deterioration, which has been reported to cause poor mechanical characteristics and reduced

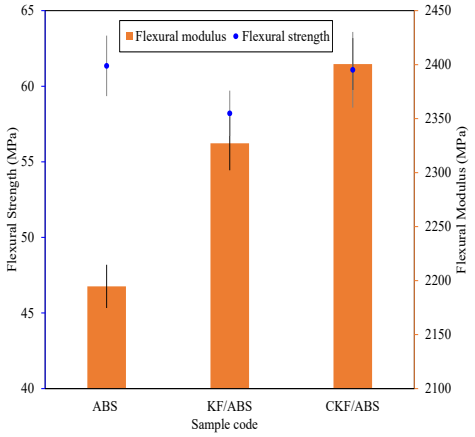

Figure 6. Flexural strength and modulus of resin-coated kenaf fiber (CKF) and uncoated kenaf fiber (KF)

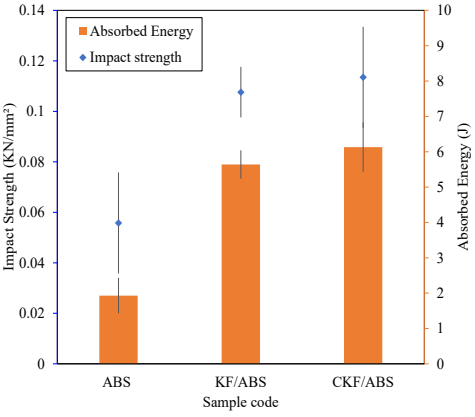

Figure 7. Impact strength and absorbed energy of resin-coated kenaf fiber (CKF) and uncoated kenaf fiber (KF)

cohesive force, untreated composites' inferior flexural capabilities may be caused by fiber breakdown at high temperatures (Pegoretti, 2021).

Impact Properties. Kenaf fiber-filled ABS composites' impact strength and absorbed energy characteristics are shown in Figure 7. The impact strength of the composites is also significantly influenced by the resin coating treatment. The values of all constituent composites were higher than those of unfilled ABS, which demonstrated that adding fillers increased the impact strength. It is a positive contrast to the tensile and flexural property results (Figures 5 and 6), where the strength values of neat ABS dropped slightly upon the incorporation of the kenaf fibers. The impact properties of CKF/ABS were superior (0.1135 KN/mm^2) compared to KF/ABS composites (0.1076 KN/mm^2) due to the epoxy coating treatment effects in improving the impact properties.

Similarly, coated kenaf (CKF/ABS) and uncoated kenaf (KF/ABS) composites had higher impact absorbed energy than clean ABS. With CKF/ABS composites, the highest energy of 6.13 J was discovered, whereas lower energies of 1.93 J and 5.64 J were observed with ABS and uncoated KF/ABS composites, respectively, an indication of the possibility that epoxy resin coatings can act as coupling agents for the kenaf, which delays the fiber thermal degradation and improves the adhesion between the epoxy coated kenaf fiber and the ABS polymer matrix for maximum impact performance. Marzuki et al. (2021) also obtained increased energy absorption, which explained the sufficient fiber-matrix interface in kenaf bast-filled composites because the basic composites of coated kenaf fibers took more energy to make compared to the raw kenaf composites.

Morphological Properties. The pristine ABS, resin-coated kenaf fiber SEM micrographs (CKF), and uncoated raw kenaf fibers (KF) reinforced acrylonitrile butadiene styrene (ABS) composites are shown in Figure 8.

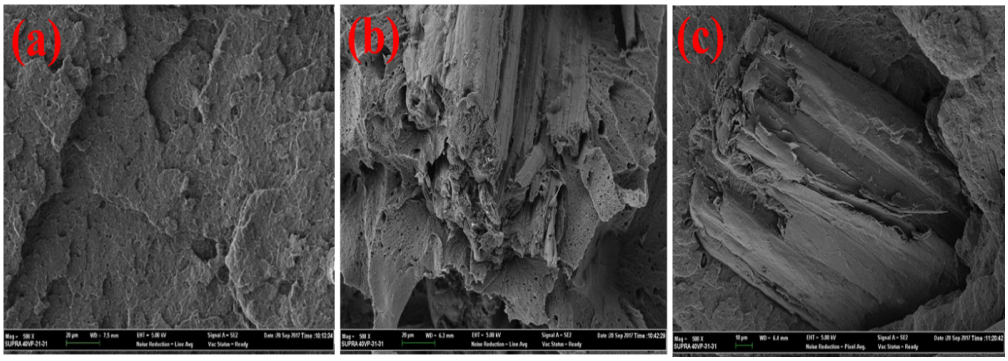

Figure 8. FESEM micrograph of fracture surface morphology of (a) unfilled ABS, (b) CKF/ABS, and (c) KF/ABS composites at 500x magnifications, respectively

Figure 8a in the SEM micrographs of the broken surfaces for the ABS matrix demonstrates that there are no reinforcing fibers in the matrix, but rather is related to the nature of the fractured surfaces for neat ABS. The results of the resin-coated fiber-reinforced composites (CKF/ABS) and raw kenaf (KF/ABS) composites are presented in Figures 8b and 8c, respectively. Figure 8b revealed cracked portions and gaps between the fiber wall and ABS matrix, which signified incompatibility. Azwa and Yousif (2013) attributed the cracks to the debonding at the fiber-matrix interface, which progressed to the surface of the composite. Figures 5 and 6 illustrate how this resulted in the composites' poor mechanical properties and inadequate bonding between the fiber and matrix. The untreated composite system shows evidence of fiber pull-out and cavities.

There is improved bonding between the coated fiber and matrix ABS molecular chain for the coated kenaf (CKF/ABS) composites (Figure 8c). An indication of the surface coating treatment effect may have activated the hydroxyl groups in the treated kenaf fiber, resulting in an effective chemical interlock with the ABS matrix. Strong fiber/matrix interfacial bonding was also seen in CKF/ABS composites, which may be the main reason for the superior mechanical performance compared to untreated composites. At a temperature of 220°C, the CKF/ABS appears to have maintained its integrity without any evidence of fiber degradation in the composite structure. It could be responsible for the superior mechanical strengths recorded for Figure 8b compared to the uncoated kenaf fiber (KF/ABS) composites.

Optical Microscopic Analysis. The optical micrographs of fiber distribution for both ABS, resin-coated kenaf fibers (CKF), and uncoated kenaf fibers (KF) in ABS matrix composite systems are presented in Figures 9a, 9b, and 9c, respectively. In both cases, it is observed that the results showed a good dispersion of fiber in the ABS phase, which can be observed from the diffused boundaries between the matrix and kenaf fibers; they were also discovered to exist as a continuous phase alongside the matrix. It is a sign that the fibers successfully fused during compounding at high pressure and temperature and effectively dispersed during melt mixing. The more successful relations of the epoxy resin with the fibers may be responsible for the superior dispersion and fusion characteristics.

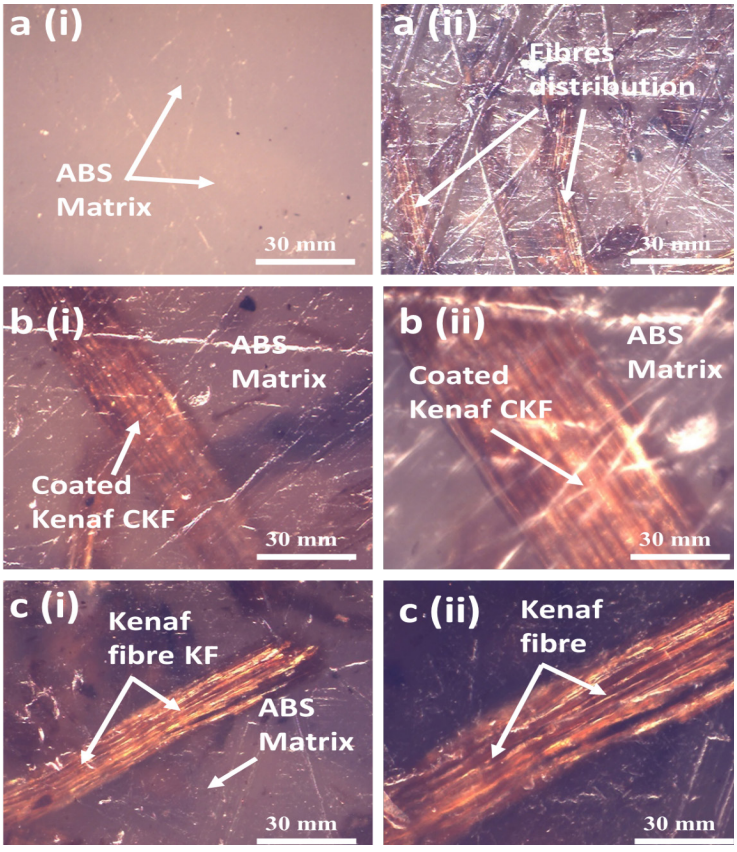

Figure 9. Optical micrograph of ABS composites system showing fiber distribution for a(i) unreinforced ABS, a(ii) reinforced composites, [b(i) & b(ii)] and [c(i) & c(ii)] coated and uncoated kenaf/ABS composites at 10x and 20x magnifications, respectively

The results have revealed a uniform and good dispersion of the fibers during processing, indicating an even distribution of the fibers in the composite system and effective participation in stress transfer (Owen et al., 2018b; Owen et al., 2019).

CONCLUSION

The thermal and mechanical properties of kenaf fiber/ABS polymer composites via resin coating treatment were studied, and it was found that the thermal and mechanical properties of epoxy-coated kenaf fiber-reinforced ABS polymer composites (CKF/ABS) were superior to the uncoated kenaf fiber composites (KF/ABS) when the kenaf fibers were loaded at 10 wt%. FTIR spectra showed how the resin coating has significantly reduced the vibrational peak intensities, which are responsible for the reduced hydrophilicity. The TGA thermograms revealed that coated kenaf fibers were thermally stable with a higher onset degradation temperature of 331.6°C, whereas raw kenaf fibers had lower thermal stability with an onset degradation temperature of 297.7°C. Due to the absence of coated kenaf fiber breakdown, the improved thermal behavior and stability of the resin-coated fiber were further substantiated by the strong interfacial bonding displayed by the FESEM micrographs. This study has addressed kenaf's fiber's poor compatibility and low thermal resistance with polymer matrices. The resultant composite is thus suitable for load-bearing and high-temperature applications.

ACKNOWLEDGEMENTS

The authors gratefully acknowledged the research support from the Biomechanical and Clinical Engineering (BIOMEC) Research Group, School of Mechanical Engineering, College of Engineering, Universiti Teknologi MARA, and the research collaboration with the Centre for Polymer Composites and Technology (PoCresT), Institute of Science IOS, Universiti Teknologi MARA (UiTM), Shah Alam, Malaysia, the Department of Polymer and Textile Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria, and the School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia (USM), Engineering Campus, Nibong Tebal, Penang, Malaysia for the use of their manufacturing and testing facilities.

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