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SHORT COMMUNICATION

Comparative Study of PLA/Kenaf Core and PLA/Kenaf Bast Flexural Properties

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ABSTRACT: Most studies on kenaf fibre composites focus on the bast due to its higher fibre yield and strength, while the core is often neglected. In this work, Polylactic Acid (PLA) matrix was reinforced with both kenaf bast and core fibres at a 49:1 wt% ratio. The fibres were chemically treated and cryo-crushed to improve bonding and dispersion. Mechanical testing revealed that treated Kenaf Core Composites (KCC) exhibited comparable flexural and impact properties to Kenaf Bast Composites (KBC), with flexural strengths of 46.19 and 46.52 MPa, respectively, and impact strengths of 5.8 and 4.4 J/m. Meanwhile, thermal analysis reported increased glass transition temperature (Tg) and crystallinity for both composites compared to neat PLA, indicating restricted polymer chain mobility and enhanced interfacial bonding. Moreover, Scanning Electron Microscopy (SEM) confirmed strong fibre-matrix adhesion and good dispersion of both fibre types. This indicates that kenaf core can perform as well as bast in composites, supporting full-plant utilization. Overall, using both bast and core can reduce waste, improve sustainability, and enhance the economic value of kenaf in bio-composite applications.

KEYWORDS: Polylactic acid; kenaf fibre; mechanical properties; chemical treatment

1 Introduction

Kenaf (*Hibiscus cannabinus* L.) is a fast-growing, eco-friendly natural fibre crop that can be harvested within four to five months and is recognized for its high CO_2 absorption and cost-effectiveness [1]. In light of the foregoing discussion, a significant research gap remains in the comparative evaluation of the two distinct fibre types of *H. cannabinus* (kenaf), namely, bast and core fiber, in reinforcement of Polylactic Acid (PLA) composites. In particular, bast fibres are characterised by their greater length, higher cellulose content (~55% for bast vs. ~49% for core), and lower lignin content, and have attracted considerable attention in composite applications [2]. In contrast, the core fiber, which constitutes a larger proportion of the stalk, has been relatively underinvestigated for its reinforcement potential [3]. The differences in morphology and chemistry suggest that fibre-matrix interactions, wetting, load transfer, and composite reinforcement efficiency may differ significantly between bast-reinforced and core-reinforced PLA composites. However, systematic studies that isolate each variable, such as fibre type (bast vs. core), fibre treatment, composite processing, and loading conditions, are scarce.

Moreover, even when core fibres have been incorporated into PLA or other polymer composite systems, many investigations do not extend to a side-by-side direct comparison of bast vs. core under the same matrix, fabrication method, and test conditions. As a result, the links between fibre type (bast vs. core), fibre-matrix interface characteristics, PLA crystallisation and thermal behaviour, and the resulting mechanical behaviours remain inadequately established. In addition, kenaf core fibers account for roughly 60% to 65% of the kenaf stalk's dry weight, which contributes to the high availability, low-cost reinforcement material [4], and possibly enhanced biodegradability [5]. However, such attributes are seldom quantified in direct comparison with bast fibre composites. Thus, this study aims to assess whether the abundant core fraction can serve as a viable and sustainable alternative reinforcement to bast fibres in PLA-based bio-composites.

Since the core accounts for roughly 60% to 65% of the kenaf stalk's dry weight, kenaf core fibres present a plentiful, low-cost reinforcement material.

2 Materials and Methods

2.1 Materials

Extrusion-grade PLA (density 1.31 g/cm^3) was sourced from Shenzhen Bright China Industrial Co., Ltd., China. Kenaf plants were supplied by INTROP, Universiti Putra Malaysia, and separated into bast and core fibres. Sodium Hydroxide (NaOH) and Hydrochloric Acid (HCl) used for treatment were obtained from Merck Group Malaysia.

2.2 Preparation of Kenaf Fibre

Kenaf bast and core fibres (KBF and KCF) were cut into 10 cm lengths. Fibers were treated with 6% NaOH for 3 h to improve hydrophobicity by breaking the extensive hydrogen bond network in the fibre structure and creating many free reactive hydroxyl groups. The fibre was then rinsed repeatedly to remove the excess NaOH. This was followed by an acid treatment (HCl) at 1.0 M for one and a half hours to hydrolyze the hemicelluloses. Subsequently, the fibres were rinsed and dried at room temperature until they achieved <8% moisture content. Following this, the fibres were cryo-crushed at −100°C in the presence of liquid nitrogen to reduce their size. Finally, the collected fibres (approximately 20 μm) were used as a reinforcement for PLA in the production of PLA-kenaf biocomposite.

2.3 Composite Production

KBF and KCF were oven-dried at 40°C for 24 h and stored in a desiccator to prevent moisture absorption. The PLA:kenaf fibre ratio is at 49:1 wt% and processed using a twin-screw extruder (150°C–160°C, 60 rpm). The extrudates were pelletized, stored in a desiccator, and then compression-moulded at 175°C for 8 min under 800 psi. The molded composites were cooled under pressure, cut to size, and designated as Kenaf Bast Composite (KBC) and Kenaf Core Composite (KCC).

2.4 Flexural Testing

For flexural testing, samples were cut to size and conditioned at 20 ± 2°C and 65 ± 5% humidity (ASTM D618-08). Flexural tests (ASTM D790-03) used specimens with dimensions of 127 mm × 12.7 mm × 3 mm. Five samples per parameter were assessed using an Instron 1195 machine (100 kN) at 20 ± 2°C, 65 ± 5% humidity. Sample dimensions were measured to 0.01 mm accuracy, supported over a 48 mm span, and loaded at mid-span at a rate of 5 mm/min.

2.5 Impact Testing

Izod impact properties were conducted in accordance with ASTM D256. Five samples for each parameter were evaluated. The test was performed on the Ray-Ran RR2500 Universal Pendulum Impact System, in a testing room with controlled temperature (20 ± 2°C) and relative humidity (65 ± 5%). For Izod impact properties, a notch was made at the center of the sample, with dimensions of 31.8 mm from the edge, with a depth of 1.54 mm. The width and thickness of each sample were measured to an accuracy of 0.01 mm. The pendulum weight was 0.898 kg, and the speed was set to 3.5 m/s.

2.6 Microscopic Observation

Scanning Electron Microscopy (SEM) was employed to observe and measure the size of the KBF and KCF, as well as to examine the failure properties of the KBC and KCC composites. The samples were coated by a sputter coater, BALTEC, SCD 005, with gold to avoid any charges. Consequently, samples were placed on a stub of an SEM (Philips XL40) with an acceleration voltage of 20 kV at room temperature.

3 Results and Discussion

Fig. 1 displays the flexural modulus of untreated and treated KBC and KCC. Untreated KBC had a modulus of 788.2 MPa, and untreated KCC had 1097.7 MPa, respectively. Fibre treatment enhances fibre-polymer adhesion by addressing the mismatch between hydrophobic polymers and hydrophilic fibres, resulting in stronger composites. Treated KBC revealed a 41.3% increase in modulus. Meanwhile, treated KCC demonstrated a slight decrease compared to the untreated ones. This suggests untreated KCC bends more easily due to intact fibre-fibre bonding. According to Pinto et al. [6], higher flexural modulus in untreated fibres can be linked to lower sensitivity of modulus to fibre-polymer adhesion compared to strength. Statistical analysis (t-test, with n = 5 and $p < 0.05$) indicated no significant difference between treated KBC and KCC, suggesting that KCC performs similarly to KBC in flexural modulus.

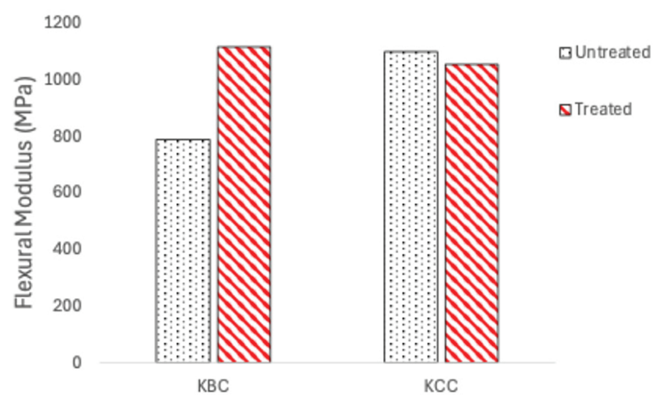

Figure 1: Comparison of flexural modulus between KBC and KCC, where small difference was detected

Fig. 2 illustrates the flexural strength of PLA-kenaf composites. The untreated KBC had 17.45 MPa and served as the control. Treated KBC presented a 166.6% improvement, while treated KCC also improved, with strength increasing by 43.4% from 31.33 MPa. The increase was due to better fibre-polymer adhesion, as treated fibres expose more fibrils for bonding, enhancing the interlocking mechanism. Statistical analysis (t-test, n = 5, $p < 0.05$) confirmed that there was no significant difference between KBC and KCC, indicating that kenaf core can perform as well as kenaf bast as a reinforcement for the composites production. Although kenaf core is often discarded for its short, porous fibres, it still demonstrates strong potential. Bast is usually preferred due to higher cellulose content (55%) compared to core (49%) [7]. In particular, cellulose contributes to the strength and stability of composites [8], and treatment helps remove amorphous segments, thereby exposing cellulose for bonding with PLA [9].

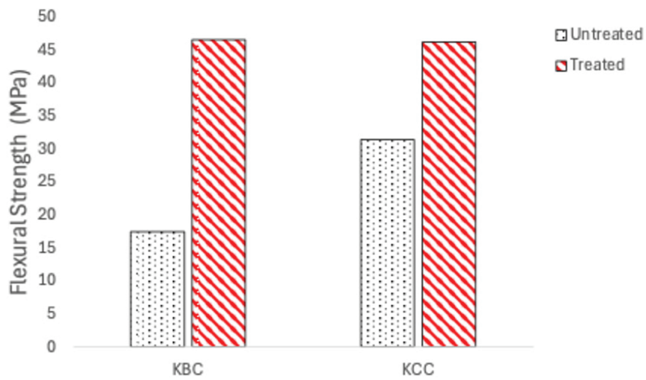

Figure 2: Comparison of flexural strength between KBC and KCC, where small difference was detected

Based on Figs. 1 and 2, chemically treated KCC exhibited flexural properties comparable to those of bast composites. Table 1 compares the treated KBC and KCC with other KCCs. The composites here had higher flexural strength than those reported by Birmin-Yauri et al. [10]. Similarly, when compared with studies by Ishak et al. [11] on unsaturated polyester and Radzuan et al. [12] on polypropylene composites, both KBC and KCC in this study demonstrated superior flexural strength. Currently, kenaf core is less used for reinforcement due to its lower cellulose content compared to bast. Since cellulose contributes to the strength and stability of composites [7], bast is often preferred. However, our previous study [13] using the Avrami index revealed that KBC and KCC exhibit similar crystallization behavior and crystallinity. This promising result suggests that kenaf core, though rarely utilized, has comparable properties to bast and strong potential for composite applications.

Table 1: Comparison of the flexural properties in this study with other research. The comparison indicates that kenaf fibre possesses higher strength as a composite reinforcement

Composites	Addition of kenaf fiber	Flexural modulus (GPa)	Flexural strength (MPa)	Increment from untreated composites (%)	
				Flexural modulus (GPa)	Flexural strength (MPa)
Treated KBC	1 wt%	1.11 ± 0.02	46.52 ± 1.0	41.3	166.6
Treated KCC	1 wt%	1.05 ± 0.1	46.19 ± 1.0	0	47.4
PLA-Kenaf core [10]	60 wt%	2.0 ± 0.1	17 ± 2.0	–	–
UP—Kenaf core [11]	10 wt%	–	28	–	–
PP—Kenaf core [12]	10 wt%	1.96 ± 0.13	17.35 ± 1.74	–	–
ABS—Kenaf core [14]	10 wt%	–	32.64 ± 2.97	–	–
PLA-Kenaf Core [15]	25 wt%	–	35–17	–	–

Note: UP—Unsaturated Polyester, PP—Polypropylene, ABS—acrylonitrile butadiene styrene.

Fig. 3 illustrates the impact strength for KBC and KCC for untreated and treated composites. Results indicate that treated KBC and KCC have higher impact strength than untreated ones, with 120% and 190% improvements, respectively. This is expected, as the treatment of the fibre has improved the bonding between the fibre and PLA. Moreover, treated KCC presents higher impact strength compared to KBC. The impact strength results demonstrate a similar trend to the flexural properties results, with treated KCC yielding a higher value of 5.8 J/m compared to KBC, which has a value of 4.4 J/m. Statistical analysis (*t*-test) has confirmed that treated KBC and KCC are not significantly different. It is indicated and supported that kenaf core can be used as much as KBC in composite production.

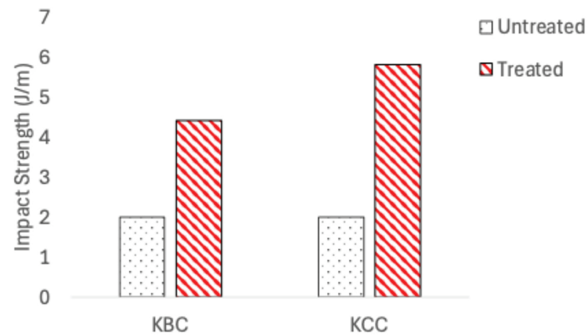

Figure 3: Impact strength of KBC and KCC for untreated and treated composites. The results indicate that the kenaf core possesses similar reinforcement capability to the kenaf bast

To support the mechanical properties, microscopic observation in Fig. 4 illustrates that KBF and KCF after chemi-mechanical treatment have indicated a reduction in fibre size. From the SEM measurement, a nano-sized fiber is visible after chemi-mechanical treatment. However, the fibre was observed to be attached to a larger-sized fibre. This is due to the dry condition of KBF and KCF, where the attachment was attributed to the formation of hydrogen bonds at respective interfaces [16]. Fig. 5 displays the SEM micrograph for the flexural failure behaviour. The KBF and KCF were dispersed in the composites. It indicates that KBF (a) and KCF (b) fibres were dispersed and embedded into PLA, which also reveals strong adhesion between the fibres and PLA. This observation has supported the mechanical properties of flexural and impact strength.

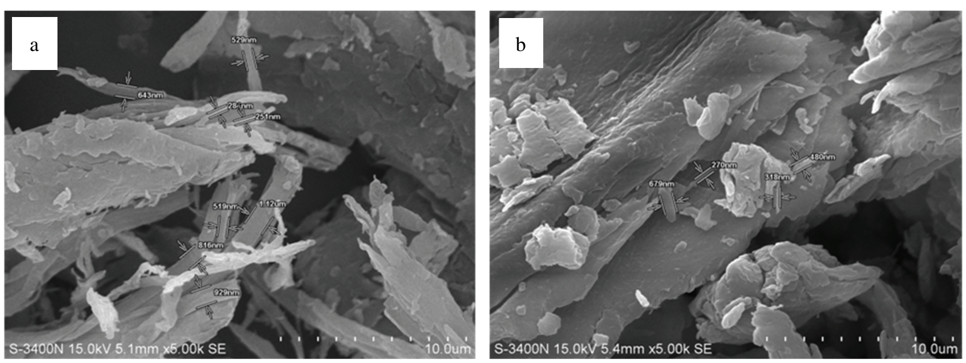

Figure 4: Measurement of (**a**) KBF and (**b**) KCF after chemi-mechanical treatment. Fiber was present on the nanoscale before being mixed with the PLA matrix

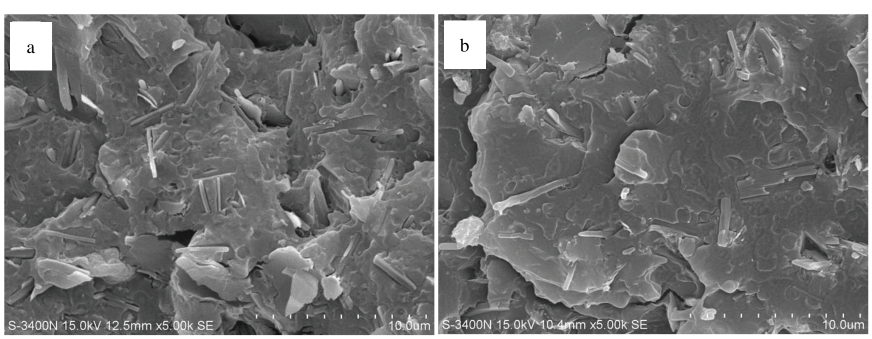

Figure 5: SEM micrograph of flexural failure behaviour. (**a**) KBF and (**b**) KCF were dispersed in the composites, and the fibre was seen embedded in the PLA matrix, which indicates strong bonding between fibre and matrix

Table 2 summarizes the glass transition temperature and percentage of crystallinity for PLA-kenaf composites. The increase in glass transition temperature for KBC and KCC indicates that the treated fibre forms a strong bond with the PLA matrix by restricting chain mobility due to efficient adhesion between the fibres and the polymer [17]. In addition, the reinforcement of KBC and KCC elevated the crystallinity to 49.46% and 47.28%, respectively, nearly doubling the crystallinity of neat PLA. Kumar et al. [18] explained that due to the modification of the fibre, the bonding between the fibre and polymer was improved. This, in turn, increases the interaction by increasing the potential hydrogen bonding and mechanical interlocking. In addition, the calculated percentage of crystallinity was consistent with the flexural properties reported earlier. With the result reported, the KBC and KCC can be utilized as an alternative product in various areas, such as automotive interiors, sports products, or marine applications that require a lightweight material with necessary strength.

Table 2: Glass transition temperature and percentage of crystallinity for neat PLA, KBF, and KCF after chemi-mechanical treatment

Samples	T_g (°C)	X_c (%)
Neat PLA	58.00	22.51
KBC	59.75	49.46
KCC	63.75	47.28

4 Conclusions

In conclusion, the flexural properties of both KBC and KCC were determined, and the treated KBC and KCC exhibited better performance than the untreated KBC and KCC. The flexural modulus and strength of treated KBC, at 1114.1 and 46.52 MPa, respectively, have yielded higher values compared to KCC (1053.3 and 46.19 MPa, respectively). However, statistical analysis (t-test) has indicated that flexural strength for both KBC and KCC is not significantly different. Impact strength also reveals that KCC has higher properties, with a value of 5.8 J/m, compared to KBC, which has a value of 4.4 J/m. On the other hand, glass transition temperature and percentage of crystallinity have supported the mechanical properties by demonstrating the improvement in KCC. Accordingly, the glass transition temperature for KBC and KCC are 59.75°C and 63.75°C, respectively, while the percentage of crystallinity for KBC and KCC are 49.46% and 47.28%, respectively. Based on the present study, KCC exhibits a comparable reinforcement characteristic to KBC as determined by its flexural and impact properties and supported by its glass transition temperature and percentage of crystallinity. Thus, KCC could be potentially used as reinforcement in polymer composite materials.

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Availability of Data and Materials: The data that support the findings of this study are available from the Corresponding Author, [Wan Nor Raihan Wan Jaafar], upon reasonable request.

Ethics Approval: Not Applicable.

Conflicts of Interest: The authors declare no conflicts of interest to report regarding the present study.

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