Mechanical Properties of Three-Layer Particleboards Containing Kenaf Core as Partial Raw Material Replacement

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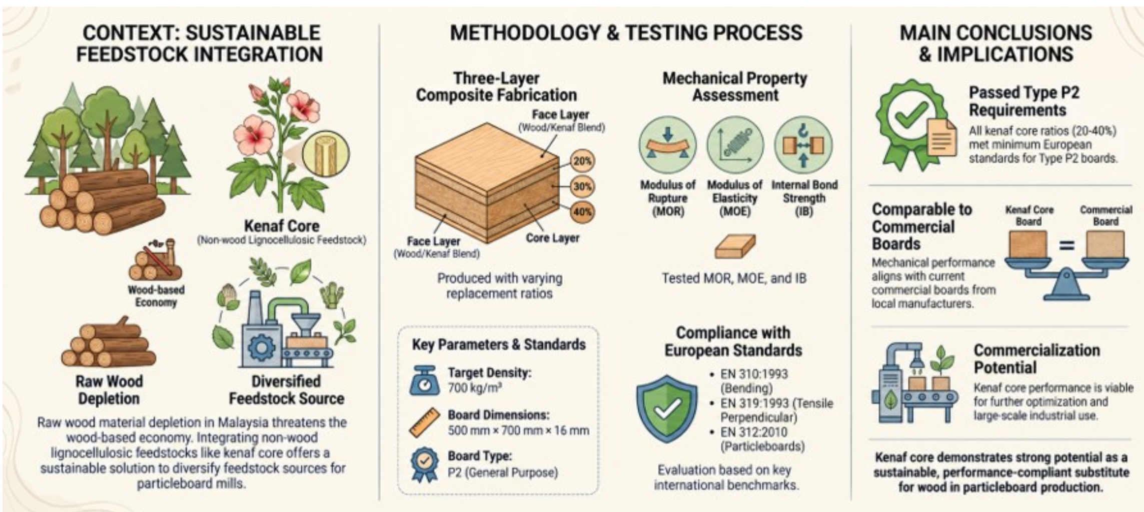
GRAPHICAL ABSTRACT



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In Malaysia, the depletion of raw materials is beginning to affect particleboard mills, as production could decrease or cease. This will impact the Malaysian wood-based economy, both locally and globally. The use of non-wood lignocellulosic feedstocks is essential to diversify feedstock sources for mills. This study investigated the mechanical properties of particleboard (density = 700 kg/m^3) made of kenaf core, rubberwood, and mixed tropical wood with different kenaf core ratios. The kenaf core ratios for the particleboards were 20%, 30%, and 40%, respectively. Boards with the dimensions 500 mm × 700 mm × 16 mm were produced. The experimental activities to determine the mechanical properties of particleboard, especially the modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB) were conducted based on European standards of EN 310:1993 and EN 319:1993 using a Universal Testing Machine. The results showed that 20%, 30%, and 40% of the kenaf core ratios passed the minimum requirements for board Type P2 based on European standards of EN 312:2010. The board performance was compared with commercial boards by local manufacturers. The kenaf core performance could be further optimized for commercialization.

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Keywords: Particleboard; Hibiscus cannabinus L.; Kenaf core; Mechanical properties; Rubberwood

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INTRODUCTION

The technology of early particleboards was characterized by the use of wood-processing residues (sawdust, chips, veneer waste) that were bonded with synthetic resins under heat and pressure. The technology has evolved to improve dimensional stability and mechanical properties by allowing for better control of particle geometry, resin content, and pressing conditions (Owodunni *et al.* 2020; Baram 2024). Since 2010, particleboard has been the subject of ongoing innovation, with a focus on waste-based raw materials, low-toxicity or bio-based binders, recyclability, and specialized products such as insulation boards and tubular products to align with circular economy and sustainability objectives. There has been a strong shift to alternative lignocellulosic feedstocks (agro-wastes, bamboo, bagasse, non-wood fibers) and hybrid sandwich boards (Gauss *et al.* 2019; Brito *et al.* 2020; Sun and Liu 2020; Papadopoulou *et al.* 2025; Tarigan *et al.* 2025).

Malaysia remains a major exporter of wood-based panels in Asia, but it faces increased competition from neighboring nations with comparable resource constraints (Sa'ad *et al.* 2019; Nuryawan *et al.* 2022). The particleboard sector in Malaysia and throughout Asia has seen substantial transformations, driven by resource constraints, sustainability imperatives, and changing consumer needs. Malaysian manufacturers are increasingly resorting to agricultural leftovers (oil palm biomass, rice husk, kenaf, bamboo) to overcome timber shortages and environmental concerns (Loh *et al.* 2010; Ahmad *et al.* 2011; Baskaran *et al.* 2017; Nadhari *et al.* 2020; Gisip 2022; Halip *et al.* 2022; Hua *et al.* 2022). The adoption of non-wood lignocellulosic resources is not only a response to dwindling forest resources but also aligns with circular economy principles and government sustainability policies (Azman *et al.* 2021; Hua *et al.* 2022; Nuryawan *et al.* 2022). Its use can reduce deforestation pressure and carbon emissions associated with conventional wood harvesting (Ramesh 2016; Mossello *et al.* 2010).

Kenaf (*Hibiscus cannabinus* L.*)* cultivation yields are typically higher than those of traditional timber species (up to 25 to 30 t/ha) and a short rotation cycle, making it an ecologically viable alternative to traditional timber (Ramesh 2016). Its low bulk density and highly porous core structure present unique mechanical challenges during hot-pressing. Previous studies have heavily explored single-layer kenaf boards at the laboratory scale, yet there remains a critical research gap in how partial replacement of wood chips with kenaf core alters the density profile and mechanical properties within a distinct three-layer formulation. The transition from a laboratory scale to an industrial model of kenaf core will facilitate the validation of new product performance and highlight the requirements for more research into processing parameters. The main objective of the study was to determine the mechanical properties of the particleboard with a target density of 700 kg/m^3, which contains kenaf core as a partial raw material replacement.

EXPERIMENTAL

Materials

Kenaf stalk was processed into kenaf cores at the Tebu Hitam, Rompin, Pahang separation lines (Fig. 1).

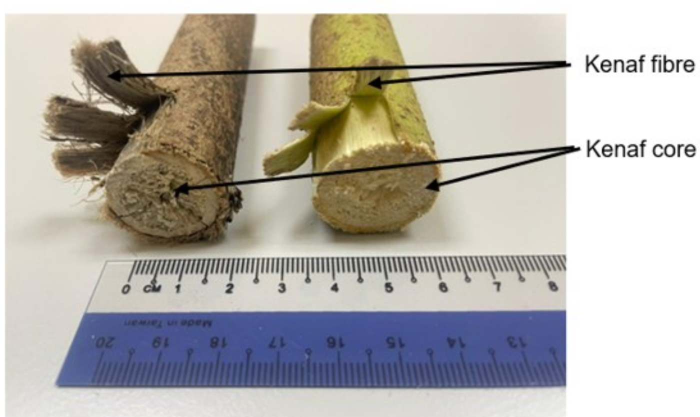

Fig. 1. Kenaf stalk with fibre and core material (left: dry stalk, right: fresh stalk)

Meanwhile, the rubberwood was obtained from smallholders, and the mixed tropical wood was sourced from sawmill waste generated from the current commercial raw material used in mills. The raw material was crushed using a chipper machine, which was followed by flaking to produce wood particles. The particles were dried to a moisture content of less than 2%.

Manufacturing Process

The wood species ratios for the particleboards were (a) 40% rubberwood: 40% mixed tropical wood: 20% kenaf core; (b) 35% rubberwood: 35% mixed tropical wood: 30% kenaf core; and (c) 30% rubberwood: 30% mixed tropical wood: 40% kenaf core. The boards were prepared with the dimensions 500 mm × 700 mm × 16 mm. Every board contained three layers. Kenaf core was replaced with some proportions of rubberwood and mixed tropical wood in sections of the upper and lower surface layers of three-layer particleboard. The surface layers (upper and lower) consisted of smaller particles than in core layer. The target board was 700 kg/m^3, which was based on the commercial industry standard. The particles were mixed with urea formaldehyde resin at 8% for the surface layer and 6% for the core layer. Table 1 details the resin and hardener in the production of particleboard. The mat was pressed in a single-opening hydraulic hot press with a platen temperature of 145, 155, and 165 °C, respectively, for 6 min. Table 2 details the pressing duration and pressure employed in the production of particleboard. After that, the boards were trimmed and allowed to cool, which was prior for testing (Fig. 2).

Table 1. Resin and Hardener

Material	Total Solid Content (%)
Urea formaldehyde resin	65
Hardener (core layer)	25
Hardener (surface layer)	7.7

Table 2. Hot-Press Time and Pressure

Level	Times (minutes)	Pressure (psi)
1	0 to 3	0 to 1800
2	3 to 5	1800 to 1200
3	5 to 6	1200 to 800

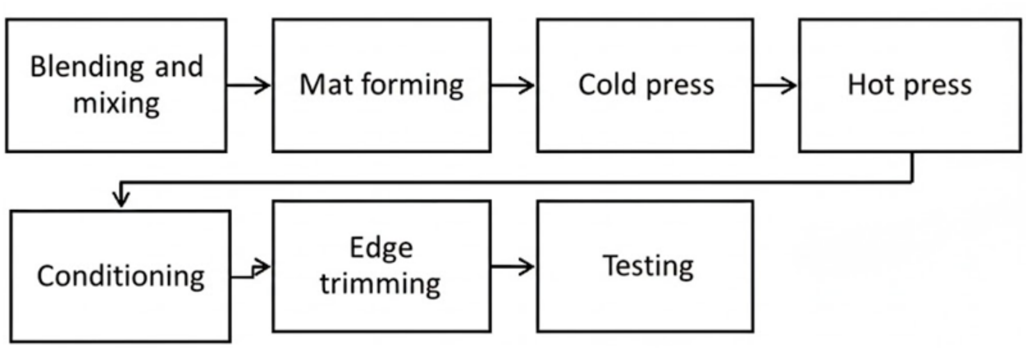

Fig. 2. Manufacturing process

Samples for Testing

The particleboards were cut to 10 specimens for each of the different kenaf core ratios, using specific sizes of specimens for the modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond (IB), which were conducted according to European standards (EN 310 1993; EN 319 1993). The universal testing machine with a load capacity of 100 kN was used in the study. The samples were cut to the dimensions 320 mm × 50 mm × 16 mm for the bending test, and the dimensions 50 mm × 50 mm × 16 mm for the IB test. The factors affecting particleboard manufacturing were analysed with an analysis of variance (ANOVA) and Duncan's multiple range test (DMRT) using the IBM Statistical Package (Armonk, USA) to determine their influence.

RESULTS AND DISCUSSION

Mechanical Properties

Table 3 shows the results of testing MOR, MOE, and IB for particleboards with a target density of 700 kg/m^3, containing different kenaf core ratios as a partial replacement for raw materials. Commercial particleboards were 50% rubberwood and 50% mixed tropical wood, as a reference specimen, which represents a 0% kenaf core ratio.

Table 3. Results of Testing

Density (kg/m^3)	Kenaf Core Ratio (%)	Bending Strength (MPa)		IB (MPa)
		MOR	MOE	
700	0 (reference)	14.16 (0.82*)	2146 (95*)	0.58 (0.08*)
	20	15.20 (1.36*)	2334 (152*)	0.46 (0.03*)
	30	15.41 (1.38*)	2408 (150*)	0.45 (0.07*)
	40	11.46 (0.66*)	2076 (98*)	0.41 (0.02*)

* = standard deviation value

Table 4 shows the mean values of the MOR, MOE, and IB for specimens with the different kenaf core ratios. The MOR value decreased with an increase in the kenaf core ratio. The 20% and 30% kenaf core ratios exhibited the highest MOR values (15.2 MPa and 15.4 MPa, respectively), comfortably exceeding the EN 312:2010 standard boards for interior fitments for use in dry conditions (Type P2) standard requirement of 11 MPa. However, a significant decrease was observed at the kenaf core ratio 40% (11.20 MPa), such that the resulting specimens barely met the minimum standard. The percentage difference of MOR between experimental data and EN Standard for every specimen was reported as 38.2% for treatment of 20% kenaf core ratio, 38.0% for treatment of 30% kenaf core ratio, and 3.3% for treatment of 40% kenaf core ratio.

Treatment of 30% kenaf core ratio showed the highest stiffness at 2410 MPa. Notably, the 20%, 30%, and 40% kenaf core ratios surpassed the EN 312:2010 (Type P2) standard requirement of MOE ≥ 1600 MPa and IB ≥ 0.35 MPa. There was a difference of 45.8% in MOE value between the experimental data and the EN Standard for 20% kenaf core ratio, 48.7% for 30% kenaf core ratio, and 31.4% for 40% kenaf core ratio. The 20% kenaf core ratio yielded the highest IB (0.46 MPa). While the IB decreased to 0.41 MPa at 40% kenaf core ratio, all experimental groups successfully remained above the minimum EN standard of 0.35 MPa. As the kenaf core ratio increased, the IB value decreased. There was a reported percentage difference of IB value of 31.4% for specimens with 20% kenaf core ratio, 28.6% for 30% kenaf core ratio, and 17.1% for 40% kenaf core ratio when comparing experimental results to the EN Standard 312:2010. Meanwhile, the commercial board as a control specimen showed the value MOR = 14.2 MPa, MOE = 2150 MPa, and IB = 0.58 MPa. Each of these values complied with the EN 312:2010 (Type P2) standard.

Table 4. Mechanical Properties of the Particleboards

Kenaf Core Ratio	Bending Strength (MPa)		IB (MPa)
	MOR	MOE	
0% (control)	14.16	2146	0.58
20%	15.20	2334	0.46
30%	15.41	2408	0.45
40%	11.50	2071	0.41
EN 312:2010 (Type P2)	**11**	**1600**	**0.35**

EN 312:2010 (Type P2) = boards for interior fitments for use in dry conditions

Statistical Significance

The ANOVA results for the effect of the kenaf core ratio on the mechanical properties are shown in Table 5. The kenaf core ratio was found to highly significantly affect the MOR, MOE, and IB.

Table 5. Summary of the ANOVA of the Mechanical Properties

SOV	Df	Bending Strength (MPa)		IB (MPa)
		MOR	MOE	
Kenaf Core Ratio	3	15.69**	8.76**	9.73**

SOV = source of variance; Df = degree of freedom; and ** = highly significantly

Effects of the Kenaf Core Ratio

The MOR and MOE are important for determining the particleboard strength. The DMRT results showed that the MOR and MOE values of the kenaf core ratios were significantly different (Figs. 3 and 4).

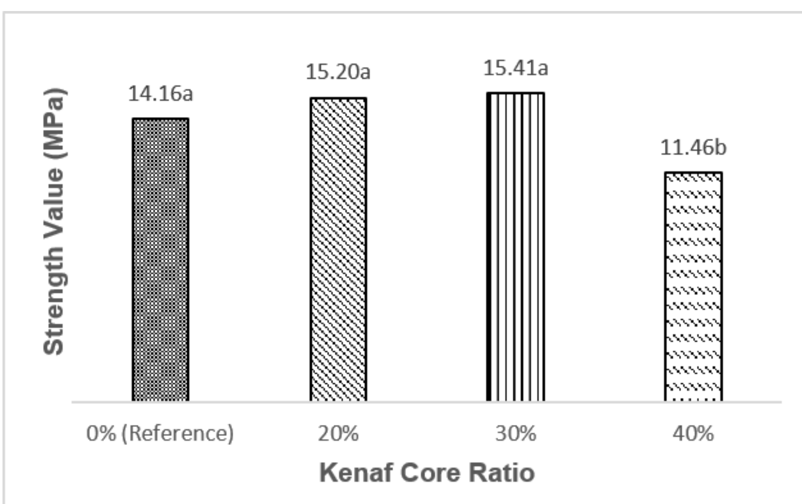

Fig. 3. Effects of kenaf core ratio on Modulus of Rupture (MOR)

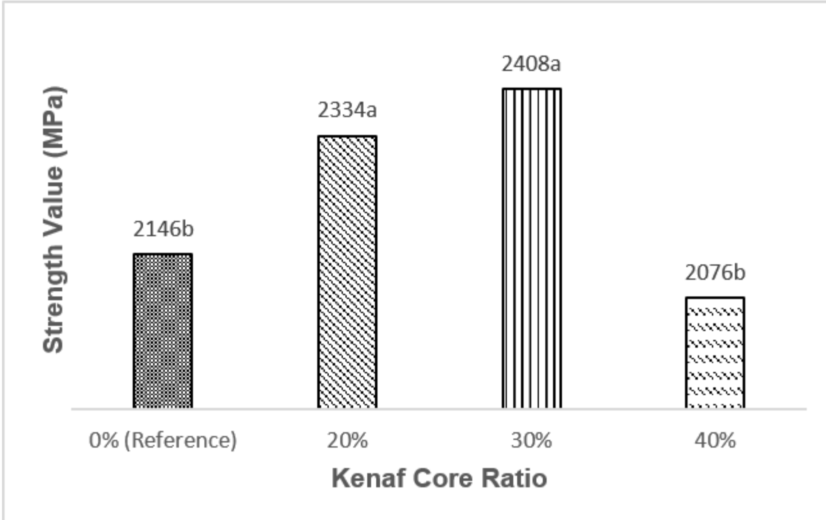

Fig. 4. Effects of kenaf core ratio on Modulus of Elasticity (MOE)

Kenaf core is consistently described as a low-density lignocellulosic material used specifically because it is lighter than conventional wood feedstocks in particleboard manufacture. Reported kenaf core density values cluster around 0.10 to 0.20 g/cm³ or about 150 kg/m³, which is far below the wood densities cited for common panel furnish such as rubberwood at 550 to 580 kg/m³ and below standard particleboard densities of 600 to 750 kg/m³ (Xu *et al*. 2003; Anyanwu *et al*. 2019; Saharudin *et al*. 2020). A sharp decline was noted at the 40% ratio, where the MOR (11.4 MPa) and MOE (2100 MPa), still meet the requirements of the EN 312:2010 (Type 2) standard. This reduction in bending strength and stiffness at higher substitution levels is consistent with the findings of Juliana *et al.* (2012), who reported that the inclusion of kenaf core beyond a specific threshold leads to a reduction in MOR and MOE due to the lower density and higher porosity of the material compared to wood particles.

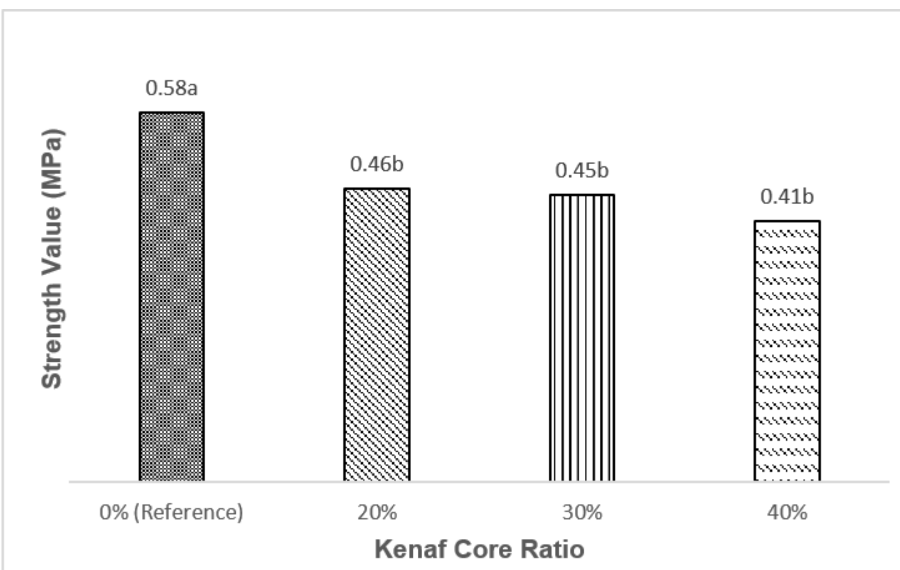

Fig. 5. Effects of kenaf core ratio on Internal Bond (IB)

Figure 5 shows the effects of the kenaf core ratio on the IB of the boards. Boards with different kenaf core ratio not significant differences in the bonding properties. Based on the findings, all boards manufactured with 20%, 30% and 40% kenaf core ratios met these requirements. The superior IB performance at lower kenaf core ratios can be attributed to better contact between the wood particles and the resin. According to Paridah *et al.* (2009), kenaf core is highly absorbent compared to rubberwood or other commercial species.

CONCLUSIONS

1. The particleboards that utilized kenaf core at ratios of 20%, 30%, and 40% had promising results compared with the existing commercial board and EN 312:2010 standards (Type P2).
2. This study demonstrated that kenaf core is suitable for use as a raw material in particleboard manufacture.
3. Future studies should focus on testing kenaf core particleboards against EN 312 standards for humid conditions (Types P3 and P5) to evaluate its long-term dimensional stability and moisture resistance.

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