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Low-density particleboard from Kenaf Core and Kelempayan Particles

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ABSTRACT. This study investigates the feasibility of utilizing kenaf core and kelempayan as alternative raw materials for the production of low-density particleboard. These rapidly proliferating species were introduced in Malaysia to guarantee a sustained supply of wood composites. This study sought to assess the impact of different board densities and particle ratios on the mechanical and physical properties of particleboard. Panels were manufactured at three densities—300, 400, and 500 kg/m^3—utilizing two particle ratios of kenaf core (KC) and kelempayan (K): 30:70 and 50:50. Urea formaldehyde (UF) resin functioned as the adhesive agent. The evaluated mechanical qualities were modulus of elasticity (MOE), modulus of rupture (MOR), and internal bonding (IB), whilst the physical properties assessed included thickness swelling (TS) and water absorption (WA), in line with Japanese Industrial Standard JIS A 5908: 2003. The findings indicated that augmenting both the density and the ratio of kenaf core enhances the mechanical and physical properties of the particleboard. Boards with a density of 500 kg/m^3 exhibited superior mechanical strength, with a modulus of elasticity (MOE) of 1127 MPa, a modulus of rupture (MOR) of 7.91 MPa, and an internal bonding (IB) strength of 2.01 MPa. Nonetheless, these denser boards demonstrated subpar performance for water absorption (133%) and thickness swelling (21.94%). Moreover, particleboards with a 50:50 ratio of KC to K surpassed those with a 30:70 ratio in both mechanical and physical properties. Notwithstanding these findings, the particleboards failed to satisfy the minimum criteria established by the standard, with the exception of internal bonding (IB).

Key words: Hibiscus cannabinus, *Neolamarckia cadamba*, particle ratio

INTRODUCTION

In light of increased awareness and subsequent demand for eco-friendly and sustainable products, the pursuit of alternative raw materials for particleboard manufacturing is rapidly intensifying. Traditionally, particleboard was produced exclusively from virgin wood; however, there is now increasing interest in utilizing agricultural and forestry waste as a sustainable alternative (Neitzel et al., 2022). This has recently provided extensive opportunities for exploration in alternative materials, such as kenaf core, for potential applications. Kenaf core and kelempayan (*Neolamarckia cadamba*) wood demonstrate significant potential to meet the need for plantation species in particleboard manufacture (Tamat et al., 2023; Gisip et al., 2022). These raw materials offer a sustainable alternative to conventional wood while possessing qualities that fulfill industrial requirements. Ongoing advances provide the prospect that these will soon be transformed into high-quality wood composites that can compete with traditional

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items. A primary concern in particleboard manufacture is its density. Standard particleboards include densities between 600 and 750 kg/m³. Low-density particleboards have a density ranging from 250 to 400 kg/m³. This low-density particleboard is valued for applications requiring this criterion. For example, it is most effective in furniture because of the preference for lighter materials that facilitate shipment and installation, particularly in ready-to-assemble furniture (Khojasteh-Khosro et al., 2020).

Furthermore, the production procedure for these light boards typically incorporates materials with low average density or utilizes sandwich panels, usually with foam or honeycomb cores (Vladimirova & Gong, 2024). Polyurethane, polystyrene foam cores, and cardboard honeycomb cores can be utilized for these lightweight properties (Khan et al. 2020). This renders the new lightweight particleboard feasible and genuinely sustainable. This research focused on examining the mechanical and physical properties of particleboards produced from a blend of kenaf core and kelempayan. The mechanical and physical performances of particleboards were assessed at targeted densities of 300, 400, and 500 kg/m³, using kenaf to kelempayan ratios of 30:70 and 50:50. Phenol formaldehyde serves as the binder at a resin concentration of 9% to ensure strength and longevity. All mechanical and physical examinations will adhere to Japanese Industrial Standard A 5908: 2003. This study has sought to evaluate the performance of new materials through testing, so providing insight into their potential broader applicability in particleboard production and the possibility of substituting more conventional, less sustainable materials.

METHODOLOGY

This study utilized kenaf core (KC) particles obtained from the Lembaga Kenaf dan Tembakau Negara in Kuantan and kelempayan (K) wood particles taken from the UiTM Jengka forest. The particleboards were manufactured using two ratios: 30% KC and 70% K, and 50% KC and 50% K. Figure 1 illustrates the flowchart of the particleboard production process.

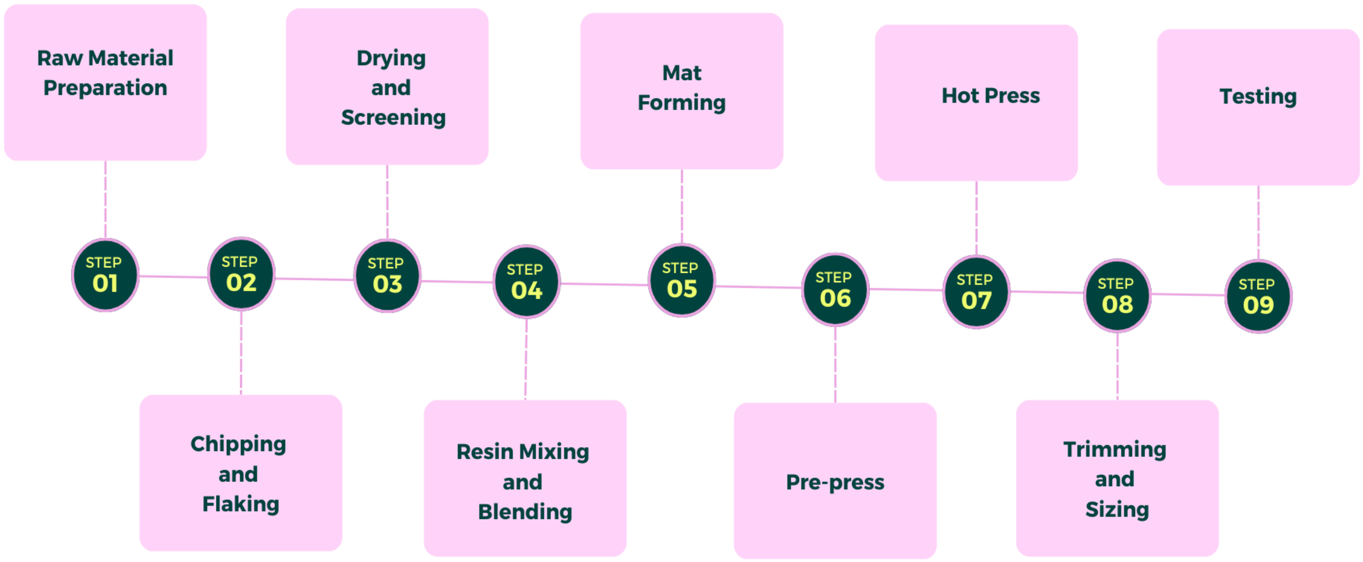

Figure 1. Low density particleboard manufacturing process

Particles Preparation

The production process commenced with the flaking of raw materials into suitably sized particles utilizing a knife ring flaker. Kenaf core and kelempayan particles were pre-dried by dispersing them in a dry, open space within our workshop. The particles were further screened using a vibrating screener after drying. The kenaf core particles were sieved to 2.0 mm, whilst all kelempayan particles were utilized in their original size without modification. The particles were subsequently oven-dried individually at 80°C for 24 hours to diminish the moisture content.

Board Formation

The specified densities of 300, 400, and 500 kg/m³ were examined at kenaf core (KC) to kelempayan (K) ratios of 30KC:70K and 50KC:50K. The KC and K particles were subsequently dried and weighed for incorporation with phenol formaldehyde resin at a 9% concentration relative to the dry weight of the kenaf core particles. The liquid was thereafter poured into a wooden mold measuring 47 cm × 47 cm × 3 cm. The mat, upon its production in the mold, was initially pre-pressed using a cold press at 350 bar pressure for 30 s. This facilitates the consolidation of the mat and eliminates all air bubbles, so ensuring perfect installation of the mat. Furthermore, it reduces structural disruption during the transfer to the hot press.

Hot Pressing

The hot-pressing temperature was 175°C. The initial pressing occurs at 1800 psi for 180 s, followed by 1200 psi for 120 s, and concludes at 800 psi for 60 s. The gradual release of pressure in stages facilitates the appropriate curing of resin and wood particles, thereby endowing the board with the necessary strength. Additionally, this procedure may guarantee that the final board's thickness meets the requirement of 30 mm. The hot-pressed boards were subsequently trimmed and crosscut into smaller parts for evaluation.

Properties Evaluation

All particleboards were evaluated for their mechanical and physical properties in accordance with the Japanese Industrial Standard JIS A 5908:2003, which classifies Type 8 particleboards as low density, namely within the range of 350 to 550 kg/m³. This category of particleboards is ideally suited for interior applications where lightweight materials are desired. Mechanical testing such as modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB) were determined. Meanwhile, physical properties such as thickness swelling (TS) and water absorption (WA) were assessed. Both testing was conducted in accordance with the procedures outlined in JIS A 5908:2003.

RESULTS AND DISCUSSION

Effects of Board Density

Figure 2 demonstrates the effect of density on the mechanical properties of particleboard, particularly the MOR, MOE, and IB values. With the increase in density, these mechanical properties also escalated. The studies indicate that increased density markedly enhanced bending strength. The samples exhibiting the maximum modulus of elasticity (MOE) values were noted at a density of 500 kg/m³ (1127 MPa), whilst the lowest MOE was reported at 300 kg/m³

(302 MPa). The MOR values for the 400 kg/m³ boards exhibited a notable disparity in comparison to those at 300 and 500 kg/m³. This is due to the greater quantity of wood in higher density boards per unit volume. The enhancement of its mechanical capabilities is attributed to the increased material density within the board (Saharudin et al., 2020). Increased particle closeness results in heightened resistance to rupture, hence enhancing board strength. A greater quantity of particles diminishes space, hence decreasing the likelihood of rupture (Lee et al., 2022). Consequently, a significant increase in density at $P \leq 0.05$ was seen in IB. The IB values peaked at 500 kg/m³ with a density of 2.01 MPa and reached a minimum at 300 kg/m³ with a density of 1.34 MPa. The enhancement in the strength of IB is attributed to the increased compaction ratio in denser boards, resulting from the incorporation of extra adhesive and wood particles. Consequently, the quality of bonding is enhanced, resulting in increased tension and ultimately stronger internal bonding (Boruszewski et al., 2022).

Figure 2. Modulus of elasticity (MOE), modulus of rupture (MOR) and internal bonding (IB) values of particleboard of different densities

Note: Means followed with the same letters (a,b,c) were not significantly different at $p \leq 0.05$

Figure 3 demonstrates the influence of density on various physical properties of the produced particleboard, including thickness swelling and water absorption. The data indicates that high-density boards exhibited greater thickness swelling after 24 hours of water immersion, attributable to their increased thickness corresponding with higher board density. Boards with a density of 500 kg/m³ had the greatest thickness swelling at 21.94%, compared to 15.48% for 300 kg/m³ and 16.62% for 400 kg/m³. The increased compression during the pressing of particleboards leads to elevated internal tension, which subsequently induces swelling (Halligan, 1970). Conversely, water absorption (WA) diminished when board density escalated from 300 to 500 kg/m³. This phenomenon can be elucidated by the "void over volume" paradigm, as articulated by Anyanwu et al. (2019). Lower-density particleboards contain larger voids, facilitating increased water absorption. As density escalates, the quantity of voids diminishes, hence decreasing the board's water absorption capacity.

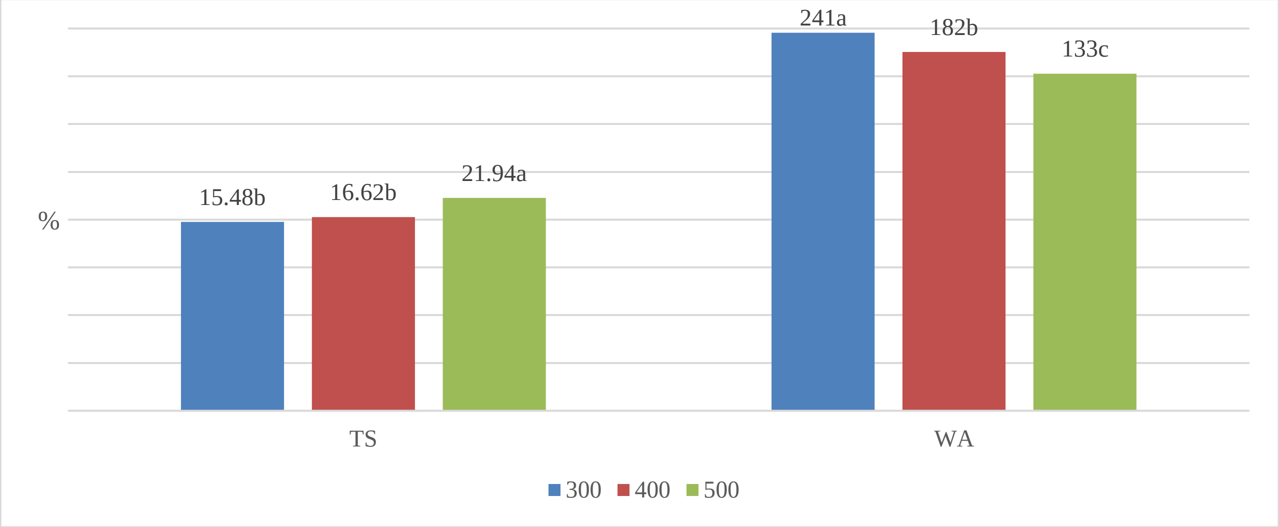

Figure 3. Thickness swelling (TS) and water absorption (WA) values of particleboard of different densities

Note: Means followed with the same letters (a,b,c) were not significantly different at $p \leq 0.05$

Effects of Particle Ratio

Figure 4 illustrates the influence of particle ratio on the bending characteristics of particleboard. The maximum modulus of elasticity (MOE) was recorded at the 30:70 ratio (676 MPa), whereas the minimum was noted at the 50:50 ratio (581 MPa). The 30:70 ratio yielded the greatest MOR at 6.49 MPa, while the 50:50 ratio recorded the lowest at 5.91 MPa. This indicates that an increase in the fraction of kenaf core particles enhances MOR strength. In terms of internal bonding (IB), the 50:50 ratio exhibited superior performance, yielding an IB value of 1.80 MPa, in contrast to 1.63 MPa for the 30:70 ratio. While the particle ratio did not markedly affect overall strength, the use of non-wood elements such as kenaf seemed to diminish the mechanical qualities of the particleboards. This corresponds with prior study indicating that an increased fraction of rubberwood particles resulted in diminished mechanical performance (Halip et al., 2014).

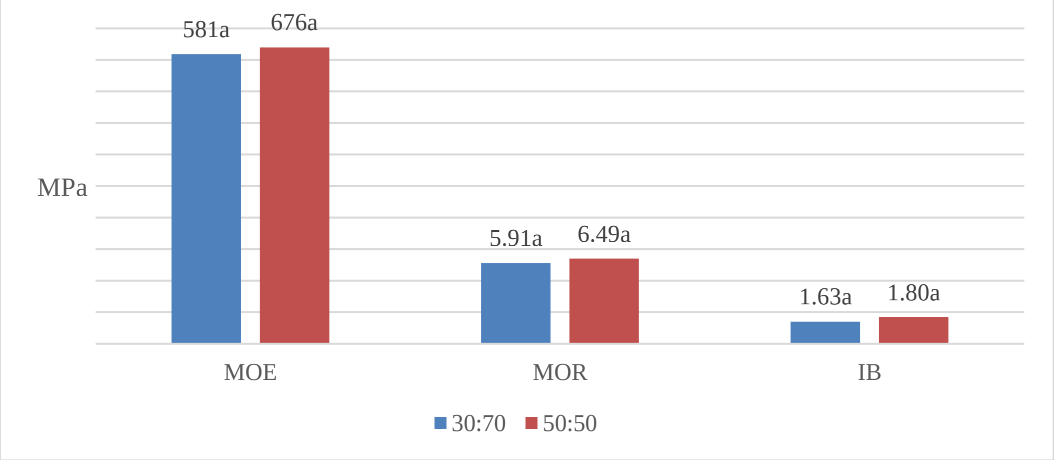

Figure 4. Modulus of elasticity (MOE), modulus of rupture (MOR) and internal bonding (IB) values of particleboard of different species ratio.

Means followed with the same letters (a) in the same column were not significantly different at $p \leq 0.05$

Figure 5 illustrates the effect of particle ratio on the physical properties of particleboard. The 50:50 ratio had the highest thickness swelling (TS) at 23.01%, while the 30:70 ratio showed the lowest at 15.60%. Although the particle ratio itself didn't significantly influence overall board properties, using 50% or less kelempayan appears to be more suitable, as higher kelempayan content tends to increase thickness swelling. For water absorption (WA), the 50:50 ratio absorbed 211% of water, whereas the 30:70 ratio absorbed 166%. This is due to smaller particles, like those from the kenaf core, absorbing more water per unit of volume than larger particles. Consequently, boards with a higher proportion of kenaf core tend to have higher water absorption. This finding aligns with Halip et al. (2014), who reported that the highly absorbent nature of kenaf core increases swelling and water uptake in particleboards.

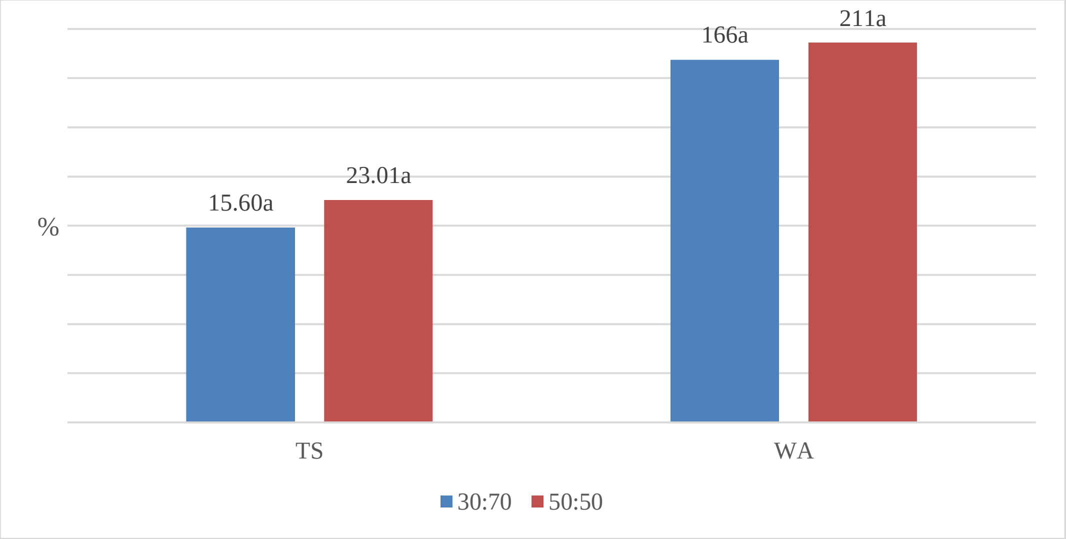

Figure 5. Thickness swelling (TS) and water absorption (WA) values of particleboard of different species ratio

Note: Note: Means followed with the same letters (a,b,c) were not significantly different at $p \leq 0.05$

CONCLUSION

This study investigated the impact of different densities and particle ratios of kenaf core and kelempayan on the mechanical and physical properties of particleboards. The results demonstrate that elevated board density markedly improves mechanical performance, with the maximum density (500 kg/m³) producing the highest modulus of rupture (MOR), modulus of elasticity (MOE), and internal bonding (IB) strength. This enhancement is ascribed to the augmented compaction of particles and improved bonding quality. Nevertheless, increased density led to enhanced thickness swelling due to the buildup of internal tension during compression, whereas water absorption diminished due to a decrease in void content. The impact of particle ratio on board attributes was very negligible. The 30:70 kenaf-to-kelempayan ratio displayed enhanced bending strength (MOR and MOE), although the 50:50 ratio showed marginally better internal bonding. Nonetheless, augmenting the fraction of kelempayan (50%) resulted in elevated thickness swelling and water absorption, indicating that a 30:70 ratio may be more advantageous for alleviating moisture-induced dimensional instability. The findings indicate that kenaf core can be successfully integrated into the production of low-density particleboard, providing a sustainable option for the creation of economical furniture and interior applications. The effective application of kenaf core in particleboard manufacturing diminishes reliance on traditional wood supplies and fosters sustainable material consumption through the repurposing of agricultural by-products. Future study should concentrate on assessing the long-term durability and industrial viability of kenaf-based particleboards relative to conventional wood-based materials to enhance their commercial potential.

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