Effect of Kenaf Parts on the Performance of Single-Layer and Three-Layer Particleboard Made from Kenaf and Rubberwood

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This study investigated the effect of kenaf parts (kenaf whole stem, kenaf core, and kenaf bast) on the mechanical and physical properties of single-layer and three-layer particleboards made from kenaf (*Hibiscus cannabinus* L.) and rubberwood (*Hevea brasiliensis*). The findings showed that the use of kenaf whole stem, which consists of both core and bast, had a positive effect on the modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB), permeability, thickness swelling (TS), and water absorption (WA) values of single-layer and three-layer panels. Single-layer admixture panels made from a combination of 70% rubberwood and 30% kenaf had greater strength and stability than single-layer homogeneous panels. The presence of rubberwood particles on surface layers significantly improved the elastic properties of three-layer panels. Panels with kenaf whole stem in the middle layer had better performance than panels with kenaf core. The MOE values of 35RW-30KWS-35RW panels were 56% and 79%, which were higher than those comprising single layers of 100% KWS and 100% KC, respectively. This study suggests that kenaf whole stem is the preferred material to be used in particleboard manufacture incorporated with rubberwood as an admixture for three-layer panels.

Keywords: Kenaf whole stem; Kenaf core; Kenaf bast; Single-layer; Three-layer

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INTRODUCTION

Non-wood plants such as kenaf, bamboo, bagasse, jose tall wheatgrass, giant reed, oil palm trunk, and rice husk have been evaluated as raw materials for particleboard manufacture in response to the depletion of wood resources (Grigoriou *et al.* 2000; Jamaludin *et al.* 2001; Zheng *et al.* 2007; Hashim *et al.* 2010; Garcia-Ortuno *et al.* 2011; Ghalehno and Nazerian 2011; Kwon *et al.* 2013). Of all the non-wood plants available, kenaf (*Hibiscus cannabinus*) has been identified as one of the potential raw materials in the manufacture of particleboard due to its fast maturity, low density of core parts (to provide a good compaction ratio), anatomical similarity to wood, and bast parts having good Young's modulus and tensile properties. Kenaf is a dicotyledonous plant and annual crop that has two components: the bast, which contains long fibres, and the core, located at the inner part of the stem, which contains short, woody-like fibres. The earliest study on kenaf core as a composite material was carried out by Sellers *et al.* (1993) in low-density composite manufacture. They revealed that more research was needed to determine its efficacy for the construction of panels and for other uses. A study by Grigoriou *et al.* (2000) found that the use of kenaf bast on the surface considerably increased the modulus of rupture and reduced the surface roughness (improved smoothness) of panels.

As reported by Ghalehno and Nazerian (2011), particleboards produced from non-wood material such as roselle stalks can meet the requirements of the European Union Standards EN 310:1993, EN 319:1993, and EN 317:1993 for MOR, IB, and TS, respectively. Non-wood material that comes from kenaf and other non-wood plants is often combined with wood (Grigoriou *et al.* 2000; Bajwa and Chow 2003; Bektas *et al*. 2005). According to these studies, panels made with mixed materials have better modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding (IB), thickness swelling (TS), and water absorption (WA) compared to 100% homogenous panels. Commonly, non-wood plant particles are mixed with wood particles at up to 30% composition to produce properties better than those of particleboards made from industrial wood particles (Sean and Labrecque 2006). Most wood particles are more slender than non-wood particles, which may contribute to the greater mechanical properties of wood particles (Wilczyński *et al*. 2011; Juliana *et al*. 2012).

Generally, particleboard made from wood has the MOE and MOR in range from 2.76 to 4.14 GPa and from 15.17 to 24.13 MPa, respectively (Cai and Ross 2010). These values are relatively lower than other panel products such as medium density fibreboard (3.59 GPa and 35.85 MPa) and oriented strand board (4.41 to 6.28 GPa and 21.8 to 34.70 MPa). Therefore, these particleboards are predicted to be used in furniture. In this study, the effects of kenaf parts (kenaf whole stem, kenaf core, and kenaf bast) towards the mechanical and physical properties of single-layer and three-layer particleboards were evaluated. Even though numerous studies have been conducted using kenaf for particleboard manufacture (Grigoriou *et al.* 2000; Bajwa and Chow 2003; Bektas *et al*. 2005; Kalaycioglu and Nemli 2006), these studies have reported mainly on the MOR, IB, and TS of particleboards made either from core, bast, or whole stem in the form of chips and strands, as opposed to the current study. Therefore, more research is needed, especially in the bonding of kenaf with other wood species and the feasibility of kenaf use in particleboard manufacturing.

EXPERIMENTAL

Particle Preparation

Four- to five-month-old kenaf stems (variety 36) were supplied by the National Kenaf and Tobacco Board, located in Kelantan, Malaysia. Meanwhile, kenaf bast in the form of crude fibres was obtained from Kenaf Natural Fibre Industry (KFI), Kelantan. Kenaf whole stems and cores were chipped to produce chips. Then, whole stems, cores, and basts were flaked using a Pallmann Ring Knives Flaker to obtain fine kenaf particles. Meanwhile, rubberwood particles were collected from the Institute of Tropical Forestry and Forest Product (INTROP), UPM Serdang, Malaysia. The particles were then dried to 5% moisture content before being separately screened using a vibrating screener, where particles passed through a 2.0-mm sieve and settled on a 0.5-mm sieve.

Single-layer Panel Manufacture

Single-layer panels were classified into homogeneous (100% kenaf) and admixture (70% of rubberwood and 30% of kenaf) types. Homogenous panels made of 100% rubberwood (100RW), 100% kenaf whole stem (100KWS), 100% kenaf core (100KC), and 100% kenaf bast (100KB) were manufactured. Twelve panels were made for each type, and each panel measured 340 mm in length, 340 mm in width, and 12 mm in thickness. Three types of admixture panels that consisted of 70RW-30KWS, 70RW-30KC, and 70RW-30KB were also manufactured. The particles were blended with 10% urea formaldehyde (UF) resin with a solids content of 65%. The target density of the panels was 0.70 g/cm^3. Single-layer panel mats were manually formed and pre-pressed at room temperature before they were compressed in a hot press at a temperature of 160 °C and a pressure of 160 kg/cm^2 for 6 min.

Three-layer Panel Manufacture

Rubberwood (RW) particles were used for the face layers of the panel, while the kenaf whole stem (KWS) or kenaf core (KC) particles were used for the middle layer of the three-layer particleboards (Fig. 1). Six types of three-layer particleboards, *i.e.*, 35RW-30KWS-35RW, 25RW-50KWS-25RW, 15RW-70KWS-15RW, 35RW-30KC-35RW, 25RW-50KC-25RW, and 15RW-70KC-15RW, were fabricated, where the dimensions and manufacturing processes were similar to the manufacturing processes of the single-layer panels.

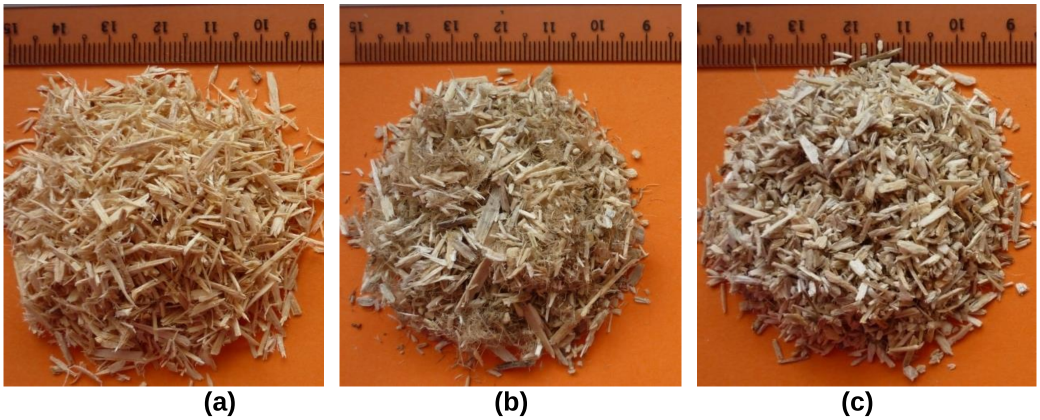

(a) (b) (c)

Fig. 1. (a) Rubberwood particles for surface layers and (b) kenaf whole stem or (c) kenaf core particles for the middle layer

Panel Evaluation

Test samples were prepared based on the Japanese Industrial Standard (JIS) A 5908: 2003 (E). The panels were conditioned at a temperature of 20 °C and a relative humidity of 65% for one week before the preparation of the test specimens (Japanese Industrial Standard, 2003). The MOR, MOE, IB, TS, and WA of the panels were evaluated using three specimens from each panel. Board density, actual moisture content, and gas permeability were also determined for all samples. Gas permeability tests were carried out using the method and apparatus used by Choo *et al*. (2013).

Data obtained were statistically analysed using Statistical Analysis System (SAS) software. Mean separation was carried out using the least significant difference (LSD) method. The level of significance (α) was set for all statistical tests at 0.05, such that probability values less than 0.05 were taken as indicative of a statistically significant difference. Because board densities may vary significantly, all data were normalised to a board density of 0.70 g/cm^3 prior to statistical analysis.

RESULTS AND DISCUSSION

Properties of Single-layer Particleboards

The mechanical and physical properties of the single-layer particleboards are presented in Table 1. The moisture content of single-layer particleboards ranged from 8.3 to 10.3%. The MOR, MOE, and IB values ranged from 2.30 to 19.6 N/mm^2, 400 to 2712 N/mm^2, and 0.02 to 1.52 N/mm^2, respectively, where the minimum requirements for general use are 8 N/mm^2, 2000 N/mm^2, and 0.15 N/mm^2. Apart from control panels (100RW), 100KWS panels exhibited higher MOR, MOE, and IB values than boards produced from homogeneous KC and KB.

Table 1. Mechanical and Physical Properties of Single-layer Particleboard[1]

Type	Properties					
	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)	Permeability (Darcy)	TS (%)	WA (%)
100RW (control)	19.6^a	2712^a	1.52^a	0.0236^c	34^d	70^d
100KWS	15.1^c	1559^c	0.51^c	0.0013^c	28^e	77^d
100KC	11.5^e	1365^c	0.09^e	0.0195^c	67^a	179^b
100KB	2.3^f	400^d	0.02^e	0.3157^a	68^a	197^a
70RW-30KWS	17.0^b	1756^b	0.90^b	0.0030^c	26^e	65^d
70RW-30KC	13.4^d	1800^b	0.42^c	0.0529^c	46^b	129^c
70RW-30KB	12.1^e	1712^b	0.27^d	0.2140^b	39^c	127^c

Means followed by the same letters (^{a,b,c,d,e,f}) in the same column were not significantly different at $p \leq 0.05$.

[1] Mechanical and physical properties were adjusted to a board density of 0.70 g/cm^3

Panels made from 100% KB had the lowest values for MOR, MOE, and IB. KB fibres, having a high specific gravity of 1.29 to 1.45 (Zimmerman and Losure 1998), were anticipated to have a lower compaction ratio. Based on a study by Maloney (1993), wood with low specific gravity (0.30 to 0.50) will produce particleboards with good bonding and other desirable properties. In agreement with this, control panels (100RW), which had a wood density ranging from 0.48 to 0.65 g/cm^3, produced panels that possessed higher mechanical properties compared to the others. This finding contradicts a previous study where particleboards made from 100% KC with 10% UF and a targeted panel density of 0.50 g/cm^3 were shown to be superior in both strength and stiffness compared to 100% RW with the same panel density and resin level (Paridah *et al*. 2009). The contradiction between the results in the current study and the study by Paridah *et al*. (2009) is attributable to their use of a lower volume of KC particles, where 10% UF resin was sufficient to be sprayed onto almost all of the KC particles, consequently producing bonding among the KC particles.

All the panel types achieved the minimum IB requirement, except those produced from 100% KC and 100% KB (Table 1). Even though 100KC panels had acceptable

MOR and similar MOE values to 100KWS due to the high compaction ratio of KC particles (low specific gravity of 0.27 to 0.31), they had low IB values because most of the resin was absorbed by the KC particles (Lips *et al*. 2009) before the resin could sufficiently spread and be transferred. As heat was applied to the KC furnish, only the adhesive on the glue line was cured, but that located in the centre was suspected to have pre-cured because of the slightly low buffering capacity characteristic of the KC material. Therefore, the IB values of the KC particleboards were slightly lower in this study. Almost all 100KC panels showed delamination at the centre of the panel (Fig. 2). This was probably caused by the high absorbent properties of KC, which may have led to adhesive starvation. Hence, KC requires more resin as the surface area increases to produce good bonding among the KC particles.

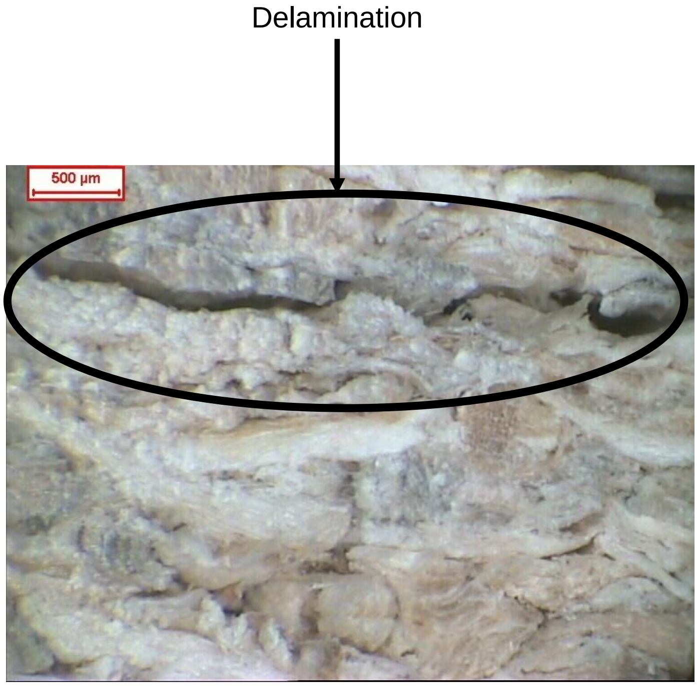
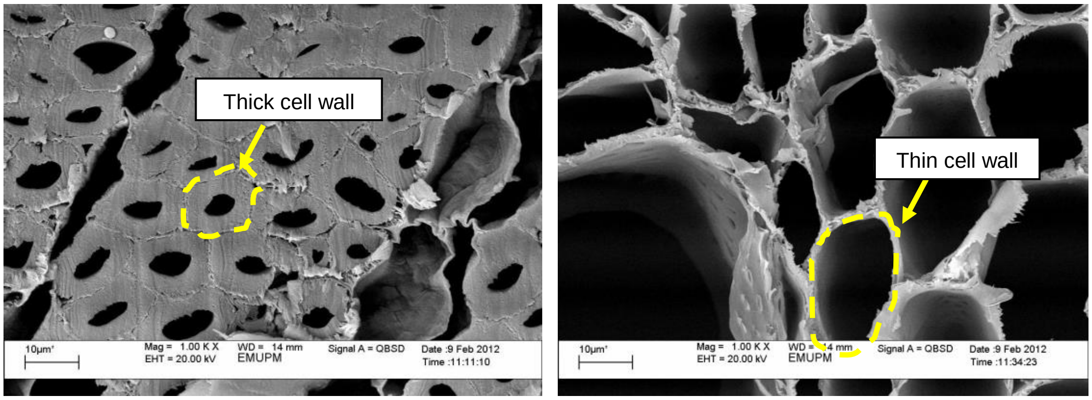


Fig. 2. Delamination in the centre of a 100KC panel

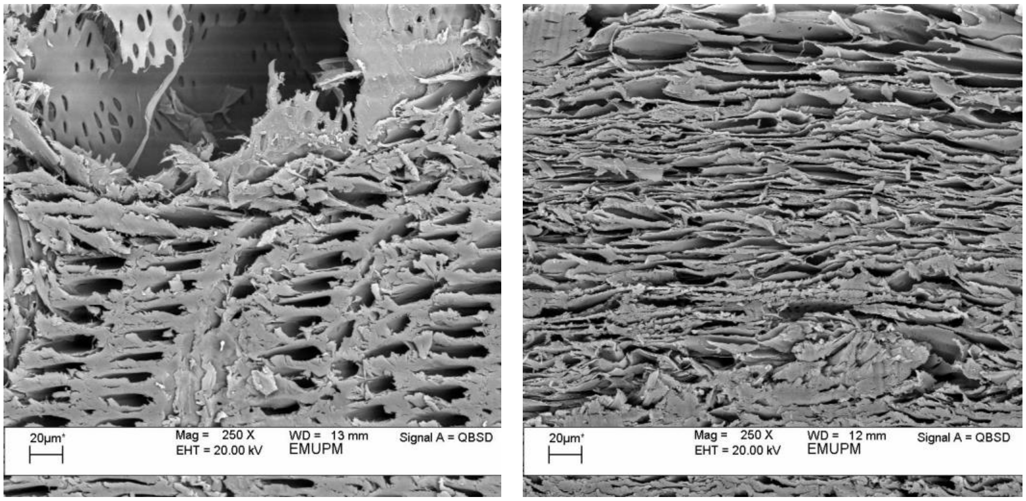
Meanwhile, in 100KB panels, thick cell walls (Fig. 3) and the presence of wax on the cuticle layer and primary wall of the kenaf outer bast surface (Tserki *et al*. 2005; Suraya and Abdul Khalil 2011) obstructed the UF resin from penetrating into the bast. In addition, Freytag and Donze (1983) reported that small amounts of residual wax may form a thin film on the surface of the fibres when heated above 60 to 70 °C, thus hindering the penetration of aqueous solutions.



(a) (b)

Fig. 3. Cross sections of (a) kenaf bast and (b) kenaf core under 1000x magnification using SEM

Under higher magnification using a scanning electron microscope (SEM), panels made from 100% KWS were observed to have more compressed cells compared to panels made from 100% RW (Fig. 4 (a) and (b)). Very flattened cells were observed as a consequence of the high compaction rate of 100KWS panels. Cells in 100KC panels (Fig. 4 (c)) were compressed, but crumpled due to soft and spongy parenchyma tissues. This particular characteristic enables KC to be easily compressed during the manufacturing process (Lips *et al.* 2009). Therefore, it was expected that the presence of stiff KB cells enabled holding and retaining of the flattened cells of KC. As mentioned previously, compaction rate is one of the important factors influencing the MOE of particleboards (Maloney 1993; Dias *et al.* 2005). Bending MOE (also known as elasticity) is a measure of the resistance to bending deflection, which is related to stiffness (Cai and Ross 2010). A well-compressed KC, together with KB, allowed 100KWS specimens to have higher MOE, MOR, and IB compared to 100KC specimens.



(a) (b)

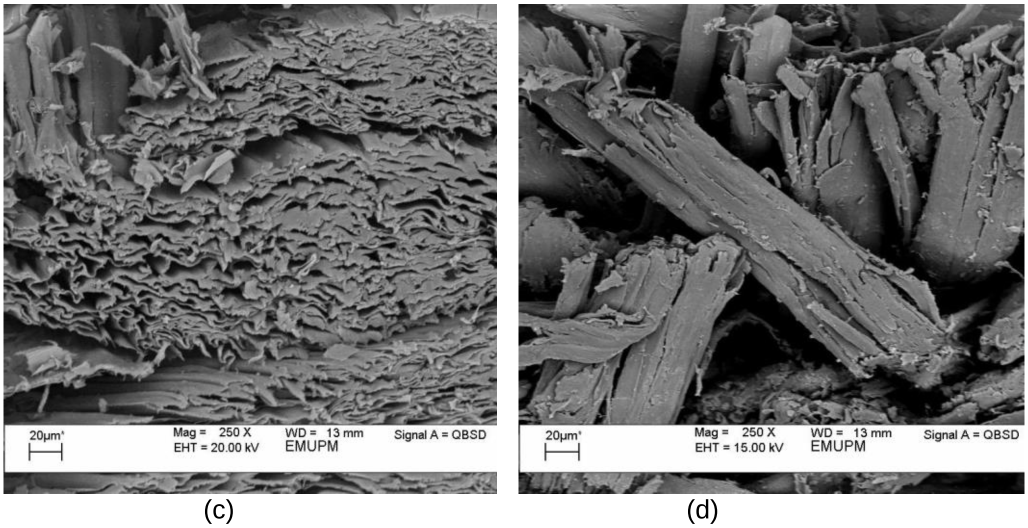


Fig. 4. Comparison of compaction on (a) 100RW, (b) 100KWS, (c) 100KC, and (d) 100KB panels at 250x magnification using SEM

Referring to Table 1, single-layer admixture panels made from 70% RW and 30% KWS possessed greater mechanical and physical properties compared to other panels. The presence of slender RW (provides strength), KC (provides high compaction ratio), and KB (provides strength and gap filling) particles were anticipated to give high MOR, MOE, and IB values and low TS and WA values for the 70RW-30KWS panels. As shown in Table 1, the mechanical and physical properties of the kenaf-based particle-boards improved when kenaf particles were mixed with RW particles. This increment was perhaps due to the higher density and more slender RW particles compared to KC particles. Therefore, the produced panels attained higher mechanical properties when RW particles were incorporated, irrespective of the type of kenaf particle used (KWS, KC, or KB).

For the physical properties, single-layer homogeneous panels made from KC and KB swelled more and absorbed more water after 24 h of soaking in cold water. Meanwhile, 100KWS and control (100RW) panels had the lowest TS and WA values, indicating that they were the most stable of the homogeneous panels. The most stable (as shown by the lowest percentages of TS and WA) were the 100KWS panels, with 28% TS and 77% WA. These values were slightly higher, although not significantly higher, than those of the control panels (100RW). The stability may be due to a better compaction of materials in the panel. In 100KWS panels, the slender and fine KB fibres were small enough to fill the gaps or voids between the thicker wedge-like KC particles, hence giving much better compaction and particle to particle bonding. This is demonstrated by the much higher IB values of these panels (0.51 N/mm^2) compared to panels made from KC (0.09 N/mm^2) and KB (0.02 N/mm^2). In admixture panels, 70RW-30KWS had the lowest TS and WA values, at 26% and 65%, respectively, and had the best performance among all the panels. The lowest permeability values belonged to boards made from KWS (homogenous and admixture). Again, this can be explained by the ability of KB particles to fill the gaps between the other particles, thus reducing the number of pores in the panels. 100KWS panels had the lowest permeability value of 0.0013 Darcy, while the highest value of 0.3157 Darcy was shown by 100KB panels. From the permeability and IB values, it can be deduced that adhesion among particles is poor in boards utilising KB.

Incorporating RW in all the kenaf-based particleboards was found to improve the properties tremendously. Among the kenaf materials, KWS was shown to be the best type of kenaf to be used in single-layer particleboard manufacture. The particleboards made from KWS consistently had relatively high strength, stiffness, and internal bonding, as well as low TS and WA values that were comparable to those attained for RW panels.

Properties of Three-layer Particleboards

In manufacturing, homogenous panels were found to have slightly lower strength and stability than admixture panels. Among homogenous kenaf panels, panels made from 100% KWS were found to be suitable as a raw material for particleboard manufacture, followed by 100KC, but with some limitations. In addition, among admixture panels, those comprising KWS and KC were found to have higher stiffness, strength, and stability, but did not meet the standard requirements for MOE. KB was not used due to the low mechanical and physical properties found in single-layer panels (Table 1). Because 100RW panels met the minimum requirement of JIS A 5908 for MOE, they were used to produce three-layer particleboards with RW particles on the surface and KC and KWS in the middle layer (Fig. 5).

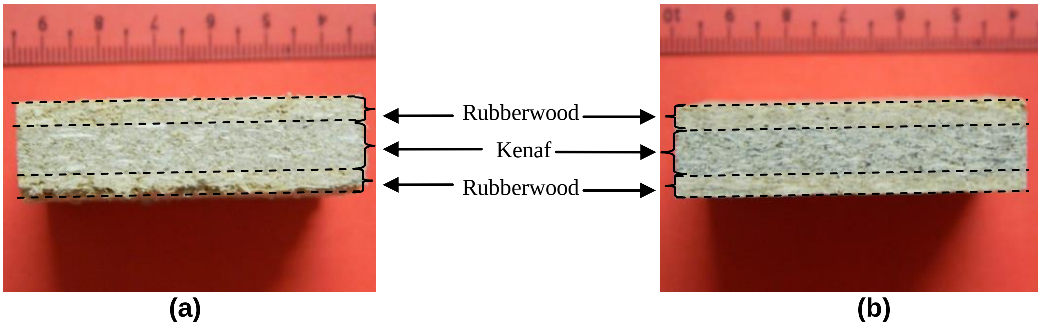


Fig. 5. Rubberwood particles at surface layers and (a) kenaf whole stem or (b) kenaf core particles for the middle layer

Figures 6 and 7 illustrate the effects of kenaf parts on the MOR and MOE values of homogeneous and three-layer particleboards. By placing KWS particles in the middle layer and RW particles on both surfaces, better performance of the three-layer panels was attained. However, increasing the amount of non-woody particles such as kenaf decreases the mechanical properties of the three-layer panels. This is in agreement with a previous study, where all mechanical properties (bending strength, IB, and screw holding strength) decreased as the amount of vine pruning particles in the middle layer increased from 12.5 to 100% (Ntalos and Grigoriou 2002). In addition, a similar result was reported where it was found that both the mechanical and physical properties of three-layer particleboards made from sunflower stalks and poplar wood deteriorated with increasing amounts of sunflower stalk particles in the panels (Bektas *et al*. 2005).

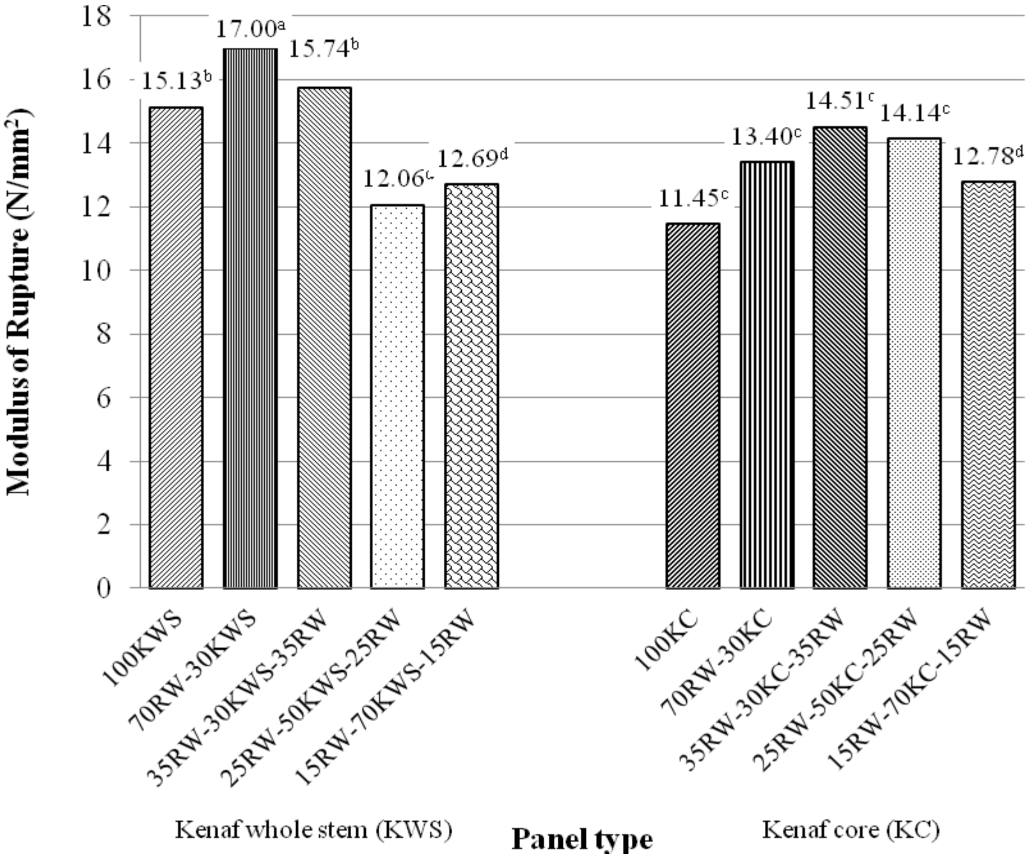


Fig. 6. The MOR values of different types of homogeneous and admixture three-layer particleboards. Means followed with the same letters (^{a,b,c,d}) in the same column were not significantly different at $p \leq 0.05$.

The three-layer panels comprising KWS were shown to be superior in terms of stiffness and strength compared to panels made with KC. The 35RW-30KWS-35RW panels with 70% RW particles at the surface layers and 30% KWS particles at the middle layers exhibited higher MOR (15.74 N/mm^2) and MOE (2438 N/mm^2) values compared to panels with lower RW particle content. It was found that the MOE of 35RW-30KWS-35RW panels was higher by 39% and 56% compared to 70RW-30KWS and 100KWS panels, respectively. By placing 30% and 70% rubberwood particles on the surfaces, the MOE values improved by 3.3 to 56% compared to single-layer homogeneous and admixture panels. This improvement was anticipated because of the slender RW particles at the surface layers (see Fig. 8(a)). However, there were no significant differences in MOE values of the three-layer particleboards with KC in the middle layer compared to the 70RW-30KC panels. In addition, single-layer admixture panels (70RW-30RW) with the same percent of RW and KWS particles (70% RW and 30% KWS) had slightly lower MOE values compared to three-layer (35RW-30KWS-35RW) panels.

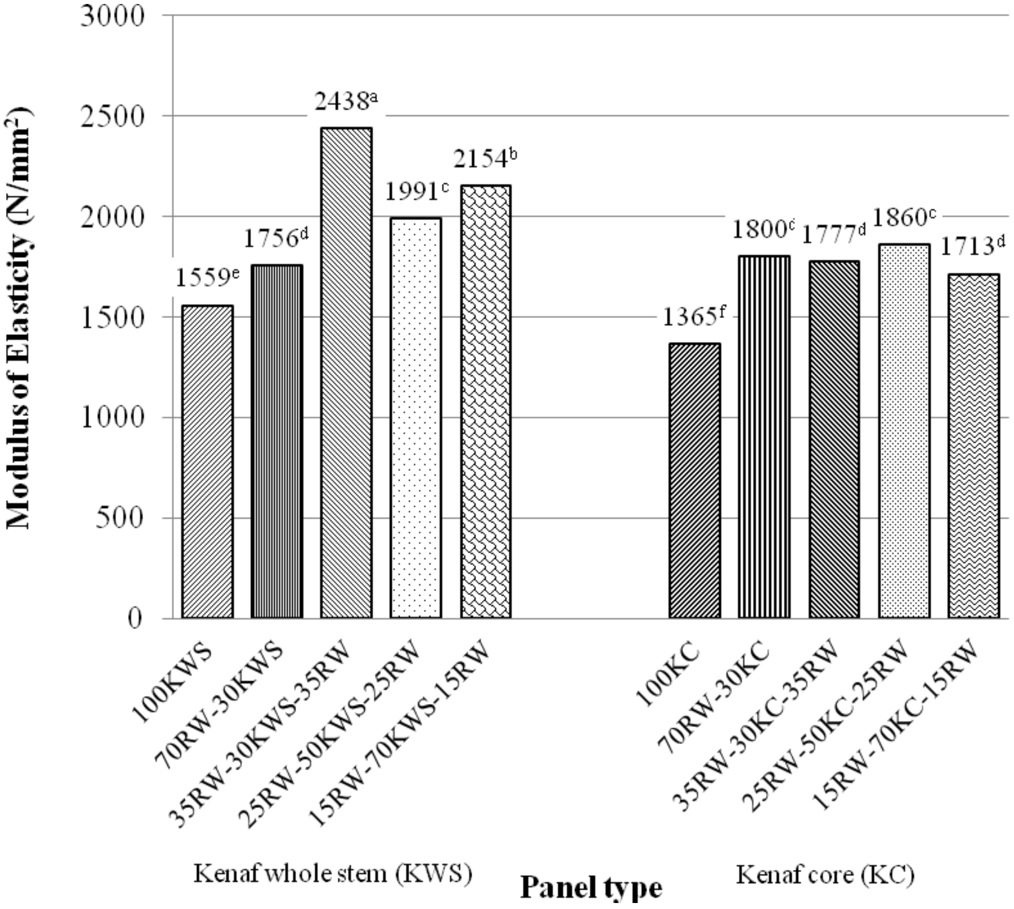


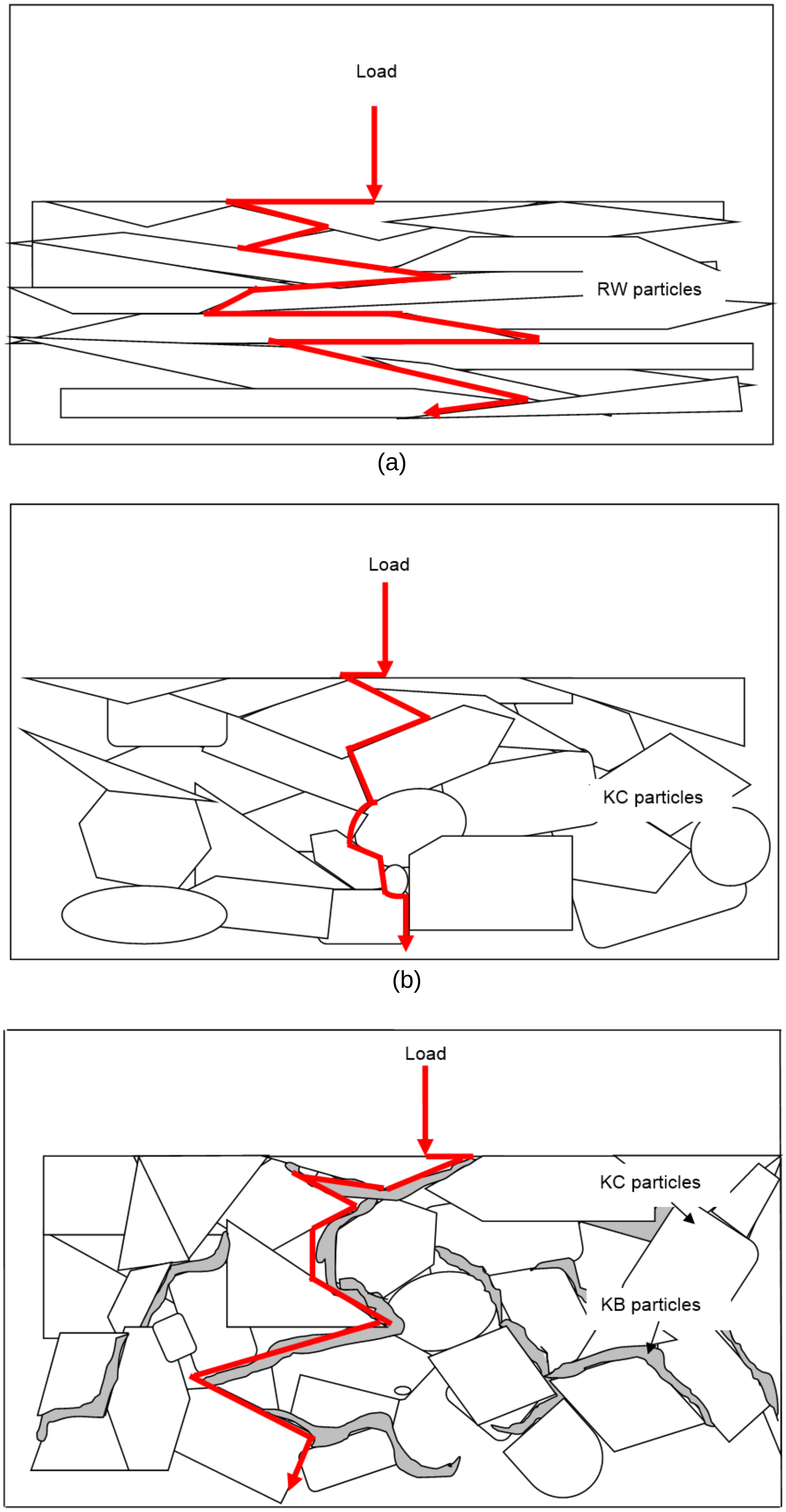
Fig. 7. The MOE values of different types of homogeneous and admixture three-layer particleboards. Means followed with the same letters (^{a,b,c,d}) in the same column were not significantly different at $p \leq 0.05$.

Results of this study suggest that the increment of the shelling ratio of RW on the surface of the panels increased the strength and stiffness of the three-layer particleboards. Particleboards with a higher shelling ratio (70%) had significantly better properties compared to those with a lower shelling ratio (30%). A similar trend was also observed in the mechanical and physical properties of panels when the shelling ratio increased from 30 to 40% (Kalaycioglu and Nemli 2006; Ghalehno and Nazerian 2011). In addition, the increase of the shelling ratio from 25 to 87.5% significantly improved the static bending, elasticity, IB, and screw holding of three-layer particleboards made from vine prunings (Ntalos and Grigoriou 2002).

Figure 8 (a) shows a schematic diagram of load transfer on the RW particles on the surface of the three-layer particleboards. The long and thin RW particles required higher loads to fracture the weakest points during bending, resulting in high bending properties of this particular panel. Previous studies also agree that longer wood particles significantly increase the bending properties of panels (Rackwitz 1963; Ong 1981). A greater amount of contact surface area on slender RW particles probably contributes to higher bending strengths. A study carried out by Wilczyński *et al*. (2011) also mentioned that using pine particles resulted in greater bending properties, as the pine has longer and thinner particles than those of willow (*Salix viminalis*). On the contrary, stout KC particles decreased the fractures on panels comprising KC particles (Fig. 8 (b)). The semi-circular end-shaped particles caused low strength values on panels manufactured with a high amount of KC (Schneider and Conway 1969). In addition, non-woody particles are reported to be shorter and wider than wood particles, which contributes to low strength properties in particleboards (Ntalos and Grigoriou 2002; Wilczyński *et al*. 2011). On the other hand, the presence of long KB particles in KWS required a higher load to facture the weakest point area compared to panels made from KC (Fig. 8 (c)).

The average IB values of three-layer particleboards ranged from 0.14 to 0.47 N/mm^2. Three-layer panels comprising KWS were found to have higher IB values than panels comprising KC particles in the middle layer (Fig. 9). However, single-layer admixture panels comprising KWS had significantly higher IB values compared to three-layer panels. According to Jamaludin *et al*. (2000), particleboards made from larger/longer particles in the core layer were found to be significantly stronger in terms of bonding strength (IB) compared to panels with smaller core particles. This explains the better strength properties of the panels with single-layer admixtures and RW particles. Increasing amounts of KC particles in three-layer particleboards significantly decreased the IB values. Despite having high absorbency (Lips *et al*. 2009), the incorporation of KC in the three-layer particleboards lowered its IB values. This can be ascribed to the low density of KC, which causes many more particles to be required to produce the same target panel density (0.70 g/cm^3). In this study, panels made from 100% KC experienced some cracks in the middle of the single layers due to accumulation of internal stresses that developed during hot pressing. However, this phenomenon was not observed in particleboards comprising KWS. The balance between the larger KC particles with swollen KB fibres generated a more uniform and well-compacted panel, as shown by the high IB values (0.51 N/mm^2).

Table 2 shows the physical properties of the three-layer particleboards with respect to homogeneous and admixture panels. With increasing shelling ratio (30 to 70%), the TS and WA values decreased, indicating better stability. Among three-layer panels, 35RW-30KWS-35RW panels had the lowest TS and WA, with values of 36% and 117%, respectively, followed by 25RW-50KWS-25RW and 15RW-70KWS-15RW panels. Again, three-layer panels comprising KWS particles had better dimensional stability properties in comparison to KC. The reason for this can be related to the low density of KC particles. Therefore, when the samples were submerged in water, low-density and highly absorbent KC increased the swelling and water uptake of the panels (Zaveri 2004; Lips *et al*. 2009). Similar to the results found for homogenous and admixture panels, the permeability of three-layer particleboards is lower in panels comprising KWS particles. As mentioned earlier, the lower number of pores and connections between pores lowers the available pathways for fluids in panels with KWS.



(a)

(b)

(c)

Fig. 8. Schematic diagrams showing load transfers of (a) rubberwood, (b) kenaf core, and (c) kenaf whole stem particleboards

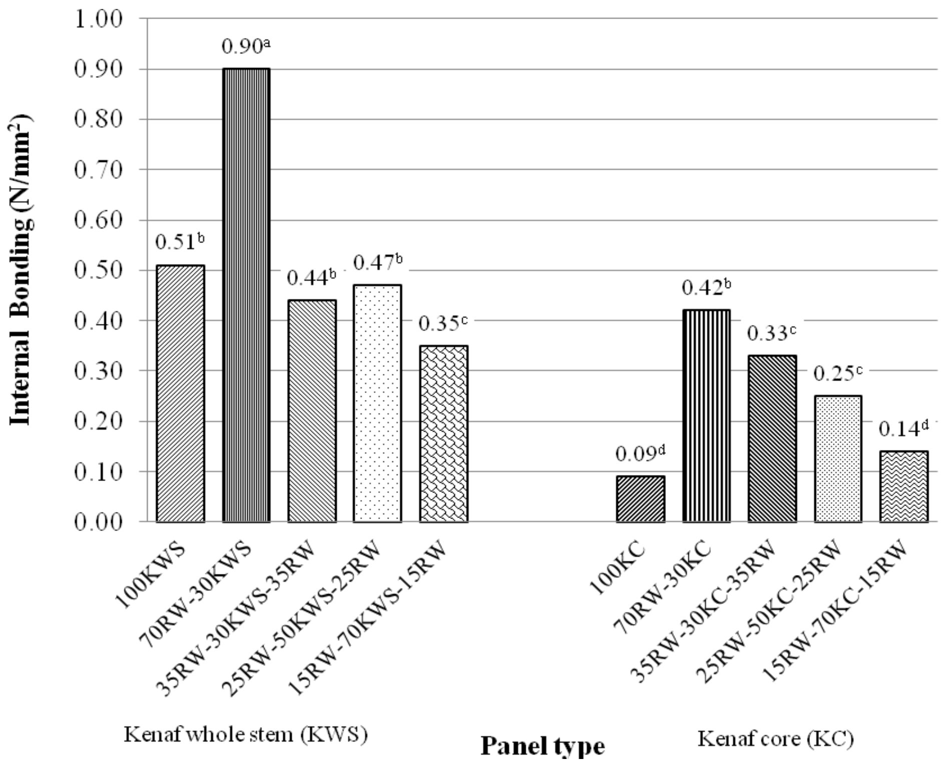


Fig. 9. The IB values of different types of homogeneous and admixture three-layer particleboards. Means followed with the same letters (^{a,b,c,d}) in the same column were not significantly different at $p \leq 0.05$.

Table 2. Physical Properties of Three-layer Particleboards in Comparison to Homogeneous and Admixture Boards[1]

Panel type	Shelling ratio (%)	Percent of kenaf (%)	Moisture content (%)	Permeability (Darcy)	Thickness swelling (%)	Water absorption (%)
100KWS	-	100 KWS	10.3^{a}	0.0013^{d}	27^{c}	77^{d}
100KC	-	100 KC	9.4^{b}	0.0195^{c}	67^{a}	179^{a}
70RW-30KWS	-	30 KWS	9.5^{b}	0.0030^{d}	26^{d}	65^{d}
70RW-30KC	-	30 KC	8.3^{d}	0.0529^{a}	46^{b}	129^{b}
35RW-30KWS-35RW	70	30 KWS	8.4^{d}	0.0045^{d}	36^{c}	117^{c}
25RW-50KWS-25RW	50	50 KWS	8.3^{d}	0.0023^{d}	46^{b}	119^{b}
15RW-70KWS-15RW	30	70 KWS	8.9^{c}	0.0025^{d}	65^{a}	125^{b}
35RW-30KC-35RW	70	30 KC	8.0^{e}	0.0399^{b}	54^{b}	114^{c}
25RW-50KC-25RW	50	50 KC	8.1^{e}	0.0260^{c}	54^{b}	136^{b}
15RW-70KC-15RW	30	70 KC	8.2^{d}	0.0208^{c}	60^{a}	167^{a}
LSD			0.29	0.0098	8.56	17.02

[1] Physical properties were adjusted to a board density of 0.70 g/cm^{3}.
Means followed with the same letters (^{a,b,c,d,e}) in the same column were not significantly different at $p \leq 0.05$.

Interestingly, homogeneous and admixture panels made from KWS and their combination gave slightly lower TS and WA values, even at the same portion of RW and kenaf compared to that of three-layer panels. This can be related to the presence of waxy layers and low wettability properties of KB particles in the panels, which prevents the absorption of water when submerged. This could have contributed to the low water absorption of the 100KWS and 70RW-30KWS panels.

CONCLUSIONS

1. Panels from KWS showed better properties overall in comparison with panels made from KC and KB.
2. The addition of rubberwood particles greatly improved various properties of the panels manufactured.
3. Three-layer panels showed the best properties followed for single-later admixture and single-layer homogenous panels.

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