Optimization of Admixture and Three-Layer Particleboard Made from Oil Palm Empty Fruit Bunch and Rubberwood Clones

Syeed Osman Al-Edrus Saiful Azry, Paridah Md Tahir and Juliana Abdul Halip

Abstract Empty fruit bunch (EFB) is a biomass that is widely available and has the potential to be used as industrial raw material especially in wood-based industries. This study focuses on producing a particleboard by incorporating EFB with two different rubberwood clones: Prang Besar (PB) 260 and RRIM 2002, respectively. PB 260 is a commercially planted clone and wood from matured (>25 year-old) trees are used by wood-based panel manufacturers. RRIM 2002 is a new clone planted at the Malaysian Rubber Board (MRB) research trial plots and consists of only 4-year-old trees. Two types of particleboards (admixture and three-layer) with different ratios were produced. The Japanese Industrial Standard (JIS-5908 2003 particleboard) was used to evaluate mechanical and dimensional stability properties of the particleboards. From the study, it was found that admixture particleboards showed superior properties compared to three-layer particleboards. Layering EFB and rubberwood significantly decreased board performance for all properties (except internal bonding). The optimum ratios of EFB and both rubberwood clones are found to be 1:1 (50% EFB: 50% rubberwood). Meanwhile, increasing the rubberwood clones ratio to 70% lowered board performance especially for EFB (30%):RRIM 2002 clone (70%) boards which showed the lowest values for all properties for both admixture and three-layer boards.

Keywords Empty fruit bunch · Admixture · Layer · Rubberwood · Particleboard · Mechanical properties · Physical properties

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K. R. Hakeem et al. (eds.), *Agricultural biomass based potential materials,*
DOI 10.1007/978-3-319-13847-3_14

Introduction

The oil palm (*Elaeis guineensis* Jacq.) is an allogamous arborescent monocot of the Arecaceae family (Hartley, 1988). In Malaysia, oil palms are normally present as single-stemmed, can reach a height of up to 20 m, and can be cultivated easily. Malaysia is the second largest exporter and producer of palm oil in the world, with a total oil palm planted area of 5.230 million hectares as of December 2013 (Table 1; MPOB 2014). The main product from oil palm is palm oil while the rest of the biomass waste is either burned (as the main energy source for power generation in palm oil mills) or dumped as organic fertilizer through natural decomposition (Yusoff 2006; Ng et al. 2012). Biomass of oil palm, namely empty fruit bunch (EFB), mesocarp fibre, palm kernel shell, and palm oil mill effluent are produced daily and are more consistent in terms of supply compared to oil palm trunks (Roslan et al. 2011). Nowadays, palm biomass have gained more attention and are being used as raw material for the production of plywood, laminated lumber, pellets, high-value chemicals, and other products (Sulaiman et al. 2011; Ng et al. 2012).

As reported by KeTTHA (2011), most of the EFB in Malaysia is used in soil mulching as an organic nutrient to reduce the input of inorganic fertilizer. Rahim (2010) mentioned that there are mills that produce particleboards from EFB in Malaysia. However, most particleboard mills in Malaysia use mainly rubberwood as the raw material as rubberwood is regarded as the conventional raw material for the production of particleboard and medium-density fibreboard (MDF) in Malaysia. Presently, Malaysia has 16 particleboard mills which use rubberwood as their major raw material (NATIP (2009). Nevertheless, with an ever-increasing demand for rubberwood, especially from the furniture industry, the rubberwood supply is being strained. Based on Ratnasigam et al. (2011), the total export value of rubberwood products grew by 39.44 % in 2009 compared to 2000. However, issues regarding the shortage of rubberwood supply are a growing concern due to declining rubber plantation areas (Ratnasigam et al. 2011). To date, various efforts have been made to incorporate the usage of rubberwood with other lignocellulose materials including EFB biomass. Oil palm EFB has been seen as an abundant, readily available, and cheap resource for board manufacturing. In terms of fibre strength properties, it has been proven to be comparable with the properties of rubberwood. In addition, high toughness and cellulose content values of EFB make it suitable for composite

Table 1 Malaysia oil palm planted area. (Source: MPOB 2014)

Year	Planted area (million hectares)
2007	4.304
2008	4.487
2009	4.691
2010	4.853
2011	5.000
2012	5.077
2013	5.230

Table 2 Empty fruit bunch and rubberwood fibre properties

Fibre properties (µm)	Empty fruit bunch[a]	Rubberwood[b]
Length	990	1249
Diameter	19.1	29.63
Lumen	–	20.28
Cell wall thickness	3.38	4.88

[a] Law et al. 2007
[b] Naji et al. 2011

applications (Sreekala et al. 2004; John et al. 2008). Fresh EFB from the mill was reported to contain 30.5 % lignocelluloses (45.0 % cellulose, 32.8 % hemicelluloses, and 20.5 % lignin), 2.5 % oil, and 67.0 % water (Ridzuan et al. 2002).

Besides the effort of many researchers to find alternative biomass to partially/fully substitute rubberwood, the Malaysian Rubber Board (MRB) also has come out with a new line of rubberwood clones to address the supply shortage of rubberwood. The series of clones are called latex-timber clones (LTC) and RRIM 2002 is one among them. Clones from the LTC series are expected to produce high latex yield and wood volume. Prang Besar (PB) 260 which has been commercially planted for decades belongs to the latex clones (LC). PB 260 is mainly planted for latex production and is only harvested and used by wood-based industry manufacturers after the trees reach the maximum tapping cycle (>25 years). Paridah et al. (2010) found that 4-year-old clones from the RRIM 2000 series produced comparable wood and particleboard properties to that of matured PB 260.

A comprehensive study on incorporating rubberwood with other biomass such as EFB could reduce the problems faced by the wood-based industry. According to Ratnasingam et al. (2007), the properties of particleboards made from 100 % of EFB are comparable with commercial particleboards and possess certain acceptable properties: mechanical, dimensional stability, and screw withdrawal. In addition, a prior study reported on the properties changes of composite panels made from EFB and rubberwood towards relative humidity, temperature, and storage time (Abdul Khalil et al. 2010). In that study, panels made from a high ratio of rubberwood exhibited superior flexural strength and flexural modulus. Juliana et al. (2012) revealed that mixing rubberwood with kenaf particles significantly improved the mechanical and physical properties of particleboard as compared to particleboard made from 100 % kenaf. Table 2 display physical properties of oil palm EFB fibres and rubberwood. However, problems may arise in the production of particleboard by incorporating EFB and rubberwood especially due to the oil traces in the EFB fibre. Mohd Nor et al. (1994) managed to produce MDF from oil palm frond and rubberwood with a 50:50 ratio. However, its properties were not satisfactory especially the internal bond (IB) and dimensional stability. Liew and Razala (1994) who also produced MDF from oil palm trunk fibres reported a similar board quality. According to Paridah et al. (2000), due to oil traces in the fibres, MDF from EFB has lower wettability, thus is more difficult to be glued or finished.

In this study, the performances of particleboards made from homogeneous and three-layer EFB with rubberwood (PB 260 clones and RRIM 2002 clone) particles were evaluated. The rubberwood clone PB 260 has been widely used as a raw material in particleboard manufacturing. Meanwhile, RRIM 2002 is one of the new clones promoted by Malaysia Rubber Board (MRB) where rubberwood can produce high timber and latex yield to be recommended for rubber plantations. However, the information on properties of this new clone as a raw material for wood-based products such as MDF and particleboard are still lacking. This chapter reports the properties of particleboard manufactured from EFB, PB 260, and RRIM 2002 clone.

Materials and Methods

Raw Material Preparation

EFB was obtained from Sabutek Sdn. Bhd., Teluk Intan, Perak. Two different rubberwood clones was used: PB 260 and RRIM 2002, respectively. PB 260 (age >25 years) wood and chips were supplied by Dongwha Fibreboards Sdn. Bhd., Nilai, Negeri Sembilan. Meanwhile, 4-year-old RRIM 2002 trees were harvested from the MRB research trial plot located at Tok Dor, Besut, Terengganu. The RRIM 2002 logs were then cut into billets and chipped using a Pallmann drum-chipper. All chips from rubberwood (PB 260 and RRIM 2002) and EFB fibre bundles were then flaked using a Pallmann knife-ring flaker to produce particles. The particles were screened using a circulating vibrator screener to classify the particles into various particle sizes retained at 0.5-, 1.0-, and 2.0-mm sieve sizes. Only particles that were retained in mesh 1.0–0.5 mm were used to fabricate the particleboards. The particles were then dried in an oven at 70 ± 2°C until the moisture content reached approximately 6%.

Manufacture of Particleboard

Admixture and three-layer particleboards $340 \times 340 \times 10$ mm in size were manufactured with a target density of 700 kg/m^3. Particleboards manufactured from 100% EFB, 100% PB 260, and 100% RRIM 2002 served as control samples. For admixture particleboard, both particles (EFB and rubberwood) were homogeneously mixed whilst three-layer particleboards were layered with rubberwood particles with EFB as the core layer. The ratio for each rubberwood clone and EFB is shown in Table 3. Urea formaldehyde (65% solid content) at 10% level was used as the resin. One percent (w/w of resin solids) ammonium chloride was used as the hardener and wax was added at 1% (w/w) of oven dry weight particles. Mats were manually formed and cold-pressed for 5 min. The mats were then hot-pressed for 7 min at 170°C. The boards were conditioned at an ambient temperature and a relative humidity of 65% until it achieved equilibrium moisture content prior to cutting

Table 3 Board types and ratios of EFB and rubberwood

Board type	Composition/ratio
Control	100 % EFB
	100 % PB 260
	100 % RRIM 2002
Admixture	50 % EFB: 50 % PB 260
	30 % EFB: 70 % PB 260
	50 % EFB: 50 % RRIM 2000
	30 % EFB: 70 % RRIM 2000
Three-layer (face : core : face)	25:50:25 (PB 260 %: EFB %: PB 260 %)
	35:30:35 (PB 260 %: EFB %: PB 260 %)
	25:50:25 (RRIM 2002 %: EFB %: RRIM 2002 %)
	35:30:35 (RRIM 2002 %: EFB %: RRIM 2002 %)

EFB empty fruit bunch

into test specimens. A total of 11 particleboard types equivalent to 33 boards were produced for the experiment.

After conditioning for 3 days at 23 °C and 65 % relative humidity, the boards were trimmed and cut into specimen sizes and evaluated for mechanical and physical properties according to the Japanese Industrial Standard, JIS A 5908–2003 (particleboard). The bending and IB strength tests on particleboards were conducted using the Instron Universal Testing Machine.

Results and Discussion

Table 4 summarizes the effects of the board type and ratio of material to the properties of the particleboards. Except for internal bonding, all properties were found to be significantly affected by the board type and ratio of materials.

Table 4 A summary of ANOVA for the effects of board type and ratio of EFB and rubberwood on the properties of particleboard

Source	df	*p*-value				
		Modulus of rupture (MOR)	Modulus of elasticity (MOE)	Internal bonding (IB)	Thickness swelling (TS)	Water absorption (WA)
Type	2	0.0001[c]	0.0001[c]	0.0336[a]	0.0033[b]	0.0001[c]
Ratio	6	0.0001[c]	0.0001[c]	0.0001[c]	0.0001[c]	0.0001[c]
Type*ratio	2	0.0001[c]	0.0001[c]	0.5191[ns]	0.0001[c]	0.0008[c]

ANOVAS analysis of variance, *EFB* empty fruit bunch

[a] Significantly different at $p \leq 0.05$

[b] Significantly different at $p \leq 0.01$

[c] Highly significant different at $p \leq 0.001$

ns Not significant $p > 0.05$

Bending Properties

The bending properties of the particleboards are shown in Table 5. From Table 5, 100% EFB has a higher modulus of rupture (MOR) but lower modulus of elasticity (MOE) compared to 100% PB 260 and 100% RRIM 2002. According to a prior study, EFB fibres cannot withstand the heavy load and this leads to the failure of that fibre which results in composite failure (Sreekala et al. 2002). This might be due to the lower α-cellulose content in EFB fibres compared to rubberwood (Abdul Khalil et al. 2010). Rubberwood is classified as light hardwood, having a specific gravity of 0.57–0.60 (Bosshard 1966; Saiful Azry 2007), while EFB has density of 0.70–1.55 g/cm^3 which is slightly higher than rubberwood. This may contribute to the improvement especially in terms of MOR in EFB boards.

After blending, the EFB with rubberwood particles, both MOR and MOE, have better properties compared to 100% EFB except admixture board made from 30% EFB to 70% RRIM. This shows that the 4-year-old rubberwood RRIM 2000 clone exhibited comparable strength and stiffness when mixed with at least 50% EFB particles. This finding also implies that, irrespective of the rubberwood age, RRIM is equally advantageous in that less strength variation results from using matured tree. However, the presence of a high ratio of rubberwood (up to 70%) particles apparently decreased the strength, but comparable to the control boards.

Apparently, a three-layer board has significantly lower strength and stiffness properties compared to admixture boards. The same trend was also observed by Juliana et al. (2012) where they found that three-layer particleboards made from kenaf and rubberwood had slightly lower MOR, MOE, and IB values compared to admixture boards. This is contributed to the presence of more void spaces in the three-layer particleboard. According to Escobar (2008), a number of voids per unit area are sufficient to cause failure under stress. However, this is in contrast with Haygreen and Bowyer (1989) who stated that the layering of multilayer particleboards

Table 5 Bending properties of particleboards

Materials	Modulus of rupture (MPa)		Modulus of elasticity (MPa)	
	Admixture	Layer	Admixture	Layer
100% EFB	22.48^b		1118^e	
100% PB 260	20.98^b		2156^b	
100% RRIM 2002	20.44^c		2145^b	
50% EFB–50%PB 260	27.54^a	16.73^d	2138^b	1716^d
30% EFB–70%PB 260	23.05^b	18.55^c	2086^b	1982^c
50% EFB–50%RRIM	27.83^a	19.88^c	2319^a	2049^b
30% EFB–70%RRIM	18.14^d	17.98^d	1645^d	1937^c
LSD	2.15		147	

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

help to increase the bending strength of the boards by altering the properties of the surface and core. Layering is one of the methods to improve the mechanical properties of most composites. It was reported that layering with wood species has significantly enhanced the MOR, MOE, and IB strength of particleboards (Nemli and Ozturk 2006).

In terms of the ratio of materials, surprisingly, the higher ratio (50 %) of EFB for both rubberwood clones for homogeneous boards showed the highest values of MOE and MOR compared to the lower ratio of EFB. This value was higher than those shown by control boards made from 100 % of each material. High stiffness and strength values might be attributed by the high aspect ratio of EFB. From observation, EFB particles are longer and slender compared to rubberwood particles. This property brings EFB to resist higher load to fracture the weakest point area of EFB board during bending. Thus, it resulted in high bending properties on this particular panel. Ong (1981) agreed with this and stated that longer wood particles significantly increased the bending properties of particleboard. As reported by John et al. (2008), EFB also has good toughness and cellulose content. In addition, the presences of a stiff material such as EFB in an admixture board might be able to potentially provide high strength to the board. However, a dramatic decrement was observed when 70 % rubberwood was incorporated. This may be due to excessive rubberwood particles to be filled between EFB particles. This finding contradicted with results obtained by Abdul Khalil et al. (2010). In their study, MDF boards made from 80 % rubberwood showed greater mechanical and physical properties compared to 50 % rubberwood.

Internal Bonding

Good compatibility can be indicated by a high modulus in composite materials (Eichhorn et al. 2001). Compatibility is one of the main problems in composite materials that commonly occur between the adhesion of the matrix and the fibres. Figure 1 illustrates the internal bonding strength of single-layer and three-layer particleboards. Apparently, homogeneous single-layer boards of EFB and rubberwood particles have good compatibility among EFB and rubberwood particles. Comparable IB values of all single-layer boards may indicate that in form of crude particles, the board has good compatibility among EFB and rubberwood particles. This finding concluded that EFB fibre can be used with PB 260 at a ratio of 30–50 %, but only 50 % with RRIM 2000 series to achieve acceptable internal strength properties.

Usually, in many cases, the weak material becomes the core material due to insignificant effect on board strength and stiffness but it may influence the IB properties. A previous study reported that EFB has low performance due to oil traces in the fibres (Paridah et al. 2000). Based on Abu Bakar et al. (2006), EFB fibres have oil residues of 4.5 % and commonly give poor bonding properties in composite manufacture. Therefore, for three-layer particleboards, EFB was placed at the core layers. Meanwhile, rubberwood was placed at the face layers since rubberwood has a higher IB value compared to EFB. Similar to an admixture board, a three-layer

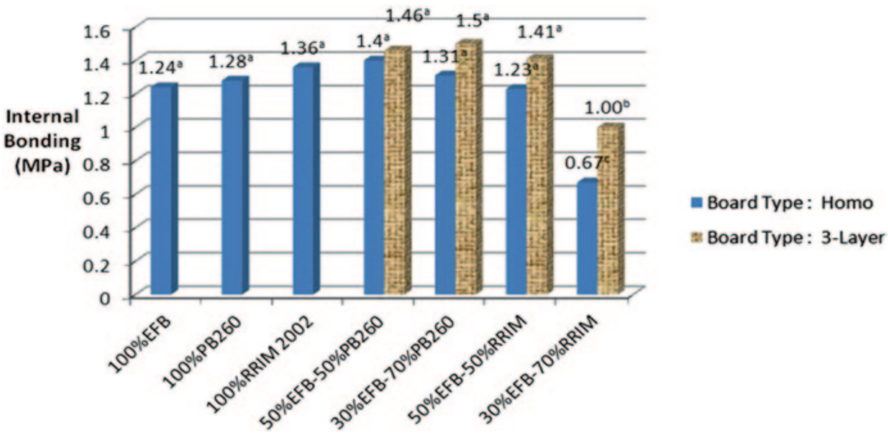

Fig. 1 Internal bonding values of particleboards. Note: Means followed by the same letters [a,b,c] in the same column were not significantly different at $p \leq 0.05$

board apparently has good internal bonding with slightly higher improvement, but not significant.

From Fig. 1, all boards were found to be not significantly different in terms of IB value, except for boards made from 70 % RRIM 2002. However, the trend for IB is reversed compared to bending values, where three-layer boards showed better properties compared with admixture and control boards.

Dimensional Stability

Thickness swelling (TS) and water absorption (WA) values are the main indicators to determine the stability of a composite. A board with low dimensional stability is indicated by high TS and WA values. Table 6 shows that the dimensional properties of the particleboards were highly affected by board type and material ratio. Apparently, single-layer and three-layer boards that consist of rubberwood particles show relatively higher TS and WA values. And interestingly, a particleboard made from pure EFB (100 % EFB) has relatively low TS and WA values compared to others. Generally, 100 % EFB has the lowest TS value, followed by boards with 50 % EFB and 30 % EFB with value ranges of 14.59 %, 16.42–18.19 %, and 15.08–26.13 %, respectively. This indicates that most boards made of EFB have low TS values.

It can be observed that boards manufactured from the RRIM 2002 rubber tree clones had higher TS values compared to the other boards. The incorporation of 30 % EFB with RRIM 2002 did not increase the board stability. However, by adding up to 50 % ratios of EFB the stability of three-layer board seem to improve. Table 6 also shows that the WA of three-layer boards was significantly higher than admixture boards. This again might be contributed to the higher percentage of void spaces in the three-layer boards which can be filled with water. Prior studies have stated

Table 6 Dimensional properties of particleboards

Materials	Thickness swelling (%)		Water absorption (%)	
	Admixture	Layer	Admixture	Layer
100 % EFB	14.59[f]		48.64[d]	
100 % PB 260	18.10[d]		57.85[c]	
100 % RRIM 2002	22.35[b]		58.03[c]	
50 % EFB–50 %PB 260	18.19[d]	17.68[d]	45.38[d]	68.17[b]
30 % EFB–70 %PB 260	15.08[e]	21.38[c]	44.73[d]	67.42[b]
50 % EFB–50 % RRIM	16.42[e]	16.47[e]	48.00[d]	76.08[a]
30 % EFB–70 % RRIM	26.13[a]	23.78[b]	70.42[a]	72.23[a]
LSD	1.58		7.28	

Means followed by the same letters [a,b,c,d,e] in the same column were not significantly different at $p \leq 0.05$

that the existence of more voids may also provide spaces which encourage water uptake (Loh et al. 2010; Saad and Izran 2012). In their studies, panels consisting of high amount of voids accommodate some of the swelling of the panel.

A study carried out by Abdul Khalil et al. (2010) showed that MDF made with rubberwood fibres were more stable compared to boards made with EFB fibres. In their study, the lower amount of holocellulose and lignin in rubberwood fibres indicate that rubberwood fibres have a lower amount of free hydroxyl groups. Interestingly, this condition was not observed in this study. Particleboards made from 100 % EFB had significantly lower TS and WA values compared to boards made from rubberwood. This might be due to the waxy surface on EFB (Adlin 2007; Nazir et al. 2013) which may resist water to penetrate into the board and reduce the water uptake. The same trend occurred when EFB fibres were layered with rubberwood particles. Overall, boards with a higher amount of EFB had relatively lower TS and WA values.

Conclusions

From the results obtained, it can be concluded that particleboards made from 100 % EFB has comparable properties with boards made from 100 % rubberwood except for the MOE. EFB particles can be mixed and layered with rubberwood (PB 260 or RRIM 2002 clone) particles up to 50 % (w/w). However, boards (both admixture and three-layer) made from 30 % EFB: 70 % RRIM 2002 gave the lowest values in almost all of the properties.

Acknowledgments The authors acknowledge the Ministry of Technology and Innovation of Malaysia (MOSTI) for supporting this research with the PR-IRPA (No: 03–04-01-0781-PR/05) scheme grant. The authors would also like to thank Institute of Tropical Forestry and Forest Products (INTROP) and Universiti Putra Malaysia for providing the researchers with the needed facilities.

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