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PROPERTIES OF MEDIUM DENSITY FIBREBOARD FROM OIL PALM EMPTY FRUIT BUNCH FIBRE

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ABSTRACT

Medium density fibreboard (MDF) is increasingly popular in the world today. In Malaysia, MDF is made using rubberwood. However, with the diminishing supply of the wood, an alternative raw material is needed. Empty fruit bunches (EFB) is a readily available waste from the oil palm industry, possibly suitable for MDF. It, however, contains residual oil which had to be removed by two pre-treatments – boiling in water and 2% sodium hydroxide (NaOH). In addition, two resin contents (4% and 6%) were used in a factorial 2 x 2 experiment. Removing the oil improved the MDF properties. Although NaOH removed more oil, its fibre was coarser with a higher bulk density (57 vs. *42 kg* m^{-3}*). The panels produced with the water pre-treated fibre therefore had better mechanical [modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding strength (IB)] and physical [water absorption (WA), thickness swelling (TS) and linear expansion (LE)] properties than the NaOH pre-treated fibre. The higher resin content (6%) also conferred better mechanical and physical properties. All the panels, except those produced with 4% resin and NaOH, easily met the minimum strength requirements by the National Particleboard Association (NPA) for MOR, MOE and IB. In contrast, all the panels were below the standards for WA and TS. The LE was also substandard with the exception of the water panels with 6% resin. Although much work remains to be done, EFB seems an eminently suitable raw material for MDF.*

Keywords: medium density fibreboard, oil palm empty fruit bunches, thermo-mechanical, mechanical and physical properties.

INTRODUCTION

The global demand for MDF is increasing rapidly. A previous census (Wadsworth, 1993) showed that there are 110 MDF mills worldwide, with an annual production capacity of more than 8.9 million cubic metres. This high demand for MDF and the ever-increasing awareness of the need to protect rain forests have required diversification of the raw materials used.

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Malaysia has about 3.5 million hectares of oil palm producing annually over 10 million tonnes of crude palm oil (CPO), making it the world's leading producer of the oil. However, CPO and its economic co-products – palm kernel oil and palm kernel cake – constitute only 10% of the crop, leaving the rest of the biomass to waste.

The biomass includes the oil palm trunks (OPT) and fronds (OPF), kernel shell, EFB, pressed fruit fibre (PFF) and palm oil mill effluent (POME). At present, these products are not only underutilized but frequently the causes of pollution as well (Husin *et al.*, 1985).

The sheer volumes of these products and their environmental friendliness cry for their use in economic products. The most available is EFB with an annual production of about 3 million tonnes (dry weight) (Husin *et al.,* 1985). EFB is the residual bunch after removal of the fruits; it constitutes 20% to 22% of the weight of the fresh fruit bunches.

On average, fresh EFB from the mill contains 30.5% lignocellulose, 2.5% oil and 67% water. The main constituents of the lignocellulose are cellulose (45%), hemicellulose (32.8%) and lignin (20.5%). Of the hemicellulose, pentosan is 27.3%. At present, EFB is mainly used as mulch, but the economics are marginal due to the high transport cost. It is seldom burnt as fuel as the shell and fruit fibre are sufficient for the oil palm mill (Ellis and Paszner, 1994; Husin *et al.,* 1985; Muthurajah, 1981).

Recently, EFB has been investigated as a raw material for building materials, solid fuel pellets, chemical products, particleboard, fibreboard, blockboard, and pulp and paper (Kobayashi *et al.,* 1985; Husin *et al.,* 1985; Muthurajah, 1981; Gabriele, 1995). Although fibreboard can be produced from any lignocellulosic material (Lathrop and Naffziger, 1949), very little is known about using EFB for it.

Lately, MDF production in Malaysia has skyrocketed. The country now has eight MDF mills, mostly using rubberwood as their major raw material. Projections show that in the near future the supply of rubberwood will not meet the demand for making MDF (Husin *et al.,* 1985). One possible solution is to use the readily available EFB instead.

Kobayashi *et al.* (1985) used EFB for making paper and found that the residual oil weakened the product. Thus, removing the oil may be necessary. In preliminary work for this study, delamination occurred during the hot pressing of panels made from unextracted EFB fibre. More adhesive (or resin) may have to be used to improve the bonding of the fibre. This study, therefore, sought to investigate the effects of fibre pre-treatment (for oil removal) and resin content (for improved bonding) on the performance of MDF made from EFB.

MATERIALS AND METHODS

Raw Material Source and Handling

EFB was obtained from Sabutech Sdn. Bhd. in Teluk Intan, Perak, and screw pressed, hammer milled and compacted into bundles. The initial moisture content was 15%. The EFB was shipped to the University of Maine at Orono for processing into MDF. Prior to processing, the long fibre (the strands were sometimes 10 cm to 30 cm) was cut with a forage harvester to below 5 cm lengths.

The resin, or adhesive, used was a water-soluble, liquid phenol formaldehyde product (GW-58CR38) from Georgia Pacific, USA. It had a solid content of 48%, viscosity of 0.19 Pa.s at 25°C, pH of 9.87 and specific gravity of 1.28.

Fibre Pre-treatment and Refining

The shortened fibre was soaked in cold water for 24 hr and separated into two portions for removing the residual oil – one boiled in water and the other in 2% NaOH, both for 30 min and under atmospheric pressure. The fibre was then transferred to a digester for conditioning before refining. In the digester, the fibre was held for 20 min under atmospheric steam to soften it in order to get a better quality pulp (less breakage of the strands occurs if the fibre is wet).

In refining, the fibre (which occurs as bundles) is teased apart into its strands with the extraneous materials binding the strands discarded. The fibre strands free of binding materials is called the pulp. The fibre was defibrated in a Sprout-Waldron thermal mechanical single disk refiner in batches of up to 4 kg each. Defibration occurred as the fibre was passed and pressed between two plates – one rotating against the stationary other. Sprout-Waldron refiner plates (D2B503 type) with a surface darn-enclosed periphery were used for the refining. Refining each batch took approximately 4 min, under atmospheric steam with a plate refining gap of 1.5 mm. Excess water was removed by centrifugation at 1500 rpm for 5 min and the pulp fluffed in a laboratory hammer mill at 500 rpm for 1 min to tease apart the pulp strands and winnow out the loosened binding materials. The material was then air dried to approximately 6% moisture content (MC).

Fibre Preparation

The dried pulp was fluffed for 2 min during which the resin was sprayed and incorporated into it at two rates - 4% and 6% w/w of resin solids to oven dry pulp – in a specially design separator/ blender described by Liang *et al.* (1994). The binding agent used was similar to that used by Chow and Zhao (1992) in the production of water-resistant MDF. All the other process parameters are as shown in *Table 1.*

Determination of Pulp Properties

The properties of the pulps extracted with water and NaOH were compared with those of non-treated pulp. The solvent extractable materials were determined by conventional soxhlet extraction on 20 g samples of the three fibres for 8 hr. Their pHs were also determined as described by Maloney (1981).

Bulk density and fibre length were determined using a gravimetric method and TAPPI standard T233 (Anon., 1989b), respectively. The average fibre lengths were also determined using a Kajaani fibre length analyser (Models FS-100) as described in Liang *et al.* (1994).

TABLE 1. PROCESS PARAMETERS USED IN THE PRODUCTION OF EMPTY FRUIT BUNCHES (EFB) MEDIUM DENSITY FIBREBOARD (MDF)

Process parameter	EFB
Pre-treatment temperature (°C)	100
Pre-treatment pressure	Atmospheric
Retention time (min)	30
Refining pressure	Atmospheric
Disc clearance (cm)	0.15
Blending condition	
Separation/fluffing time (min)	2
Total fluffing and blending time (min)	10
Resin pH	9.87
Solids content (%)	48
Pressing condition	
Temperature (°C)	204
Time to stop (s)	28
Pre-bump dwell time (s)	40
Number of bumps	2
Time between bumps (s)	40
Cure time (s)	280

Board Preparation

Mats (410 mm x 410 mm) of the pulp were hand-formed in a 300 mm deep box. This was done by sieving the pulp into the box through a 6 mm mesh, aided by some hand pressure forcing it through. When the box was full, the pulp was manually compacted to 130 to 150 mm height, and then placed in a manual steam-heated press. Further pressing was done with a platen temperature of 204°C and the press schedule in *Table 1*. The target thickness was 0.64 cm and the target density 881 kg m^{-3}. Four panels were produced for each combination of resin level and pre-treatment.

Testing and Analytical Procedures

The panels were trimmed to 36 cm x 36 cm squares and later cut into test pieces of the sizes in *Table 2*. Prior to mechanical and physical property testing the specimens were conditioned at 65% relative humidity and 20°C. Three point static bending MOR and MOE and IB strength tests were performed to ASTM D1037-89 Standard (Anon., 1989a) using an Instron machine. TS and WA measurements were made by laying the specimens in water for 24 hr at ambient temperature, in conformance with ASTM D1037-89. Linear expansion was measured along the lengths at the equilibrium conditions of 50% and 90% relative humidity and 27°C, according to ASTM D1037-89. The IB samples were profiled for their density gradients on a gamma-ray direct scanner prior to testing.

The data for the panel properties were statistically analysed by the SYSTAT program (Anon., 1992) using analysis of variance (ANOVA) (2 x 2 factorial experiment). The differences in properties were compared at the 0.05 significance level by Turkey's multiple range test using a fixed-effect model.

TABLE 2. SIZES AND NUMBERS OF SAMPLES USED FOR TESTING THE PROPERTIES OF EMPTY FRUIT BUNCHES (EFB) MEDIUM DENSITY FIBREBOARD (MDF)

Test	Sample size (cm)	Samples/ panel	Number/ treatment	Total
Bending	20 x 5 x 0.64	4	16	64
IB	5 x 5 x 0.64	5	20	80
Water absorption and thickness swelling	15 x 15 x 0.64	2	8	32
Linear expansion	20 x 5 x 0.64	2	8	32

One-way ANOVA at the 0.01 significance level was also used in the analysis for bulk density, pH and oil content, and Pearson's correlation coefficient to determine the relationships between the test results.

RESULTS AND DISCUSSION

Pulp Properties

The average values for bulk density, pH, oil content and length for the fibre before and after the pre-treatments are presented in *Table 3*. One-way ANOVA revealed that at the 0.01 significance level the bulk density of the NaOH fibre (57 kg m^{-3}) was higher than that of the water stock (42 kg m^{-3}). The lower bulk density from the water fibre was due to the fineness of the pulp. In the NaOH pre-treatment, the fibre remained less broken up and clumpier. Nevertheless, both pre-treatments reduced the fibre bulk density from that of the original fibre (α = 0.01) although all three were above the recommended minimum of 32 kg m^{-3} (Suchland and Woodson, 1985).

The NaOH fibre was significantly less acidic (α = 0.01), contained slightly less residual oil and was coarser than the water fibre.

Panel Properties

In *Tables 4* to *6*, the average mechanical and physical properties of the panels are presented. ANOVA showed that the two factors tested – pre-treatment and resin content - significantly influenced all the properties except density. However, the pre-treatment x resin content interaction was not significant (α = 0.05) for all the properties evaluated.

Overall, the panels made from the water fibre performed better than those made from the NaOH pre-treatment. *Table 4* shows the superiority of the former for MOR, MOE and IB. The differences between the two pre-treatments in strength could have stemmed from the differences in bulk density. The water panels also had lower WA, TS and linear expansion than the NaOH panels (α = 0.05).

The effects of resin level on the physical and mechanical properties of the panels are given in *Table 5*. MOR, MOE and IB increased significantly (α = 0.05) with the resin content. The results were expected and in line with the results from previous research (Chow and Zhao, 1992; Woodson, 1976). The physical properties (WA, TS and LE) also improved significantly with the resin content (α = 0.05).

TABLE 3. CHEMICAL AND PHYSICAL PROPERTIES OF FIBRES AFTER PRE-TREATMENT

Property	EFB	Hot water	2%NaoH
Bulk density (kg m^{-3})[a]	106A	42B	57C
pH[a]	5.48A	5.45A	6.56B
Oil content (%)[a]	1.1A	0.14B	0.07B
Single fibre length (mm)[b]	0.25		
Fibre length class[c]			
>28 mesh (>0.595 mm)		71.76	87.42
28- 48 mesh (0.595-0.297 mm)		10.07	4.20
48-100 mesh (0.297-0.149 mm)		5.24	3.93
100- 200 mesh (0.149-0.074 mm)		3.49	1.44
<200 mesh (< 0.074 mm)		9.44	3.01

Notes: [a] Values with the same following letters are not significantly different at α=0.01.
[b]Arithmetic mean of 30 000 fibres; [c]Average of two determinations.

TABLE 4. MECHANICAL AND PHYSICAL PROPERTIES OF EMPTY FRUIT BUNCHES (EFB) MEDIUM DENSITY FIBREBOARD (MDF) AFTER PRE-TREATMENT WITH WATER AND NaOH

Pre-treatment	Mechanical properties			Physical properties					Density
	MOR MPa*	MOE GPa*	IB KPa*	WA2 %*	WA24 %*	TS2 %*	TS24 %*	LE50/90 %*	Davg kg m^{-3}
Water	37A	2.7A	806A	48B	58B	19B	22B	0.42B	1041A
2% NaoH	22.8B	1.9B	696B	71A	78A	37A	40A	0.58A	1057A

Notes:* Values with the same following letters are not significantly different at α=0.05.
MOE=modulus of elasticity; MOR=modulus of rupture; WA2, WA24=water absorption at 2 and 24 hr; TS2, TS24=thickness swelling at 2 and 24 hr and LE=linear expansion at 50/90% RH and Davg=average density.

TABLE 5. MECHANICAL AND PHYSICAL PROPERTIES OF EMPTY FRUIT BUNCHES (EFB) MEDIUM DENSITY FIBREBOARD (MDF) MADE WITH DIFFERENT RESIN CONTENTS

	Mechanical properties			Physical properties					Density
Resin content	MOR MPa*	MOE GPa*	IB KPa*	WA2 %*	WA 24%*	TS 2%*	TS 24%*	LE 50/90%*	Davg kg m^{-3}
4	25.7B	2.0B	104B	64A	71A	32A	34A	0.59A	1057A
6	32.8A	2.6A	114A	53B	64B	22B	25B	0.41B	1041A

Notes:* Values with the same following letters are not significantly different at α=0.05.
MOE=modulus of elasticity; MOR=modulus of rupture; WA2, WA24=water absorption at 2 and 24 hr; TS2, TS24=thickness swelling at 2 and 24 hr and LE=linear expansion at 50/90% RH and Davg=average density.

TABLE 6. COMPARISON OF MECHANICAL AND PHYSICAL PROPERTIES OF EMPTY FRUIT BUNCHES (EFB) MEDIUM DENSITY FIBREBOARD (MDF) AFTER PRE-TREATMENT WITH WATER AND NaOH WITH THE NATIONAL PARTICLEBOARD ASSOCIATION (NPA) STANDARDS

	Mechanical properties				Physical properties					Density
Pre-treatment	RESIN %	MOR MPa	MOE Gpa	IB KPa	WA2 %	WA24 %	TS2 %	TS24 %	LE 50/90	Davg kg m^{-3}
Hot water	4	34.3	2.4	785	52	61	25	27	0.58	1041
	6	39.9	3.0	827	44	56	15	17	0.31	1057
2% NaOH	4	19.3	1.7	655	78	82	41	44	0.60	1089
	6	27	2.2	689	64	74	33	36	0.56	1025
MDF Property Standards NPA	-	24.1[a]	2.1[a]	689[a]	-	14.6[b]	-	11.9[b]	0.35[a]	-

Notes: MOE= modulus of elasticity; MOR= modulus of rupture; WA2, WA24=water absorption at 2 and 24 hr; TS2, TS24=thickness swelling at 2 and 24 hr and LE=linear expansion at 50/90% RH; Davg=average density; [a]National Particleboard Association 4-73.(11); [b]Average values for higher density MDF (0.88SG).

Table 6 summarizes the effects of both the pre-treatment and resin level. As the fibre bulk densities were above the recommended minimum, all the panels, except those produced with 4% resin and NaOH, easily met the minimum strength requirements by the NPA (Anon., 1973) for MOR, MOE and IB. In contrast, all the treatments were poorer in WA and TS than what was obtained by Borchgrevine (1983). According the NPA standards (Anon., 1973), the linear expansion of all the panels was substandard with the exception of the water panels with 6% resin. The variability in the physical properties could, at least in part, be due to the water repellent used in the commercial boards on which the reference standards were established.

In all the boards, the vertical density gradient from direct gamma-ray scanning was U-shaped (*Table 7*). But between the treatments, there were no significant differences in the densities in both the surface and core.

The relationships between all the properties are presented in *Table 8*. MOR, MOE and IB were positively related with each other, but negatively related to all the physical properties. The relationships between WA and TS, and between WA and LE were positive at P • 0.05. TS and linear expansion were positively related at P • 0.05, but both properties were not related to the vertical density gradient.

CONCLUSION

This study showed that it is possible to produce MDF from EFB fibre. Pre-treatment of the fibre to remove its residual oil significantly improved the MDF performance and eliminated delamination during consolidation of the panels. NaOH was more effective than water for removing the oil, but a poorer fibre was obtained with a higher bulk density which also reduced the mechanical and physical properties. As expected, using more resin improved the physical and mechanical properties. The non-significant difference in average panel density and density gradient eliminated these physical properties as the causes of variation between the panels. The dimensional stability of most of the panels was below the commercial standard.

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TABLE 7. SUMMARY OF DENSITY GRADIENT TEST RESULTS

Pre-treatment	Resin %	Density gradient DL*	DM*	DR*
		— — — — — — —	kg m^{-3}	— — — — — — —
Water	4	1089A	865A	1137A
	6	1169A	865A	1185A
2% NaoH	4	1153A	926A	1169A
	6	1121A	897A	1121A

Notes: *Values with the same following letters are not significantly different at α=0.05.
DL=density at the top, DM=density in the mid-panel, DR=density at the bottom.

TABLE 8. RELATIONSHIPS BETWEEN THE MECHANICAL AND PHYSICAL PROPERTIES AND VERTICAL DENSITY GRADIENT OF MEDIUM DENSITY FIBREBOARD (MDF) FROM EMPTY FRUIT BUNCHES (EFB)

Parameter	MOE	MOR	IB	WA2	WA24	TS2	TS24	LE
MOE	1.000							
MOR	**0.954**	1.000						
IB	**0.778**	**0.784**	1.000					
WA2	**-0.704**	**-0.794**	**-0.650**	1.000				
WA24	**-0.670**	**-0.756**	**-0.618**	**0.981**	1.000			
TS2	**-0.816**	**-0.858**	**-0.712**	**0.922**	**0.902**	1.000		
TS24	**-0.777**	**-0.828**	**-0.681**	**0.902**	**0.876**	**0.985**	1.000	
LE	**-0.507**	**-0.528**	**-0.501**	**0.588**	0.489	**0.716**	**0.721**	1.000
DL	0.408	0.416	0.220	-0.143	-0.183	0.343	0.366	-0.390
DR	0.217	0.279	0.058	-0.130	-0.151	0.298	0.275	-0.401
DM	-0.027	-0.077	-0.237	0.358	0.355	0.174	0.175	-0.154

Notes: Values in bold are significant at P • 0.05.
MOE= modulus of elasticity; MOR= modulus of rupture; WA2, WA24=water absorption at 2 and 24 hr; TS2, TS24=thickness swelling at 2 and 24 hr; LE=linear expansion at 50/90% RH and Davg=average density.
DL= density at the top; DM=density in mid-panel; DR=density at the bottom.

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