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Mechanical and Dimensional Stability Properties of Medium-Density Fibreboard Produced from Treated Oil Palm Empty Fruit Bunch

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Abstract: Empty Fruit Bunches (EFB) are readily available residues from palm oil industry and have tremendous potential to be used as fibre raw material for Medium-density Fibreboard (MDF) manufacture. However, some of the properties of the MDF produced from EFB have been reported to be relatively inferior to those made from rubberwood, presumably due to presence of residual oil in the fibres. In this study, the effects of EFB fibre treatment (soaking in 2% NaOH, boiling in water, both soaking and boiling) on the properties of MDF were investigated. The MDF was manufactured using urea formaldehyde (UF) as a binder and bonded at three resin levels: 8, 10 and 12%. The boards were tested according to MS Standards 1787: 2005. The results revealed that the refined EFB fibres were short and relatively hard. It was also observed that these fibres tend to conglomerate and formed a small loosely wrapped fibre lumps. Among the treatments used, boiling in water was able to significantly improve the dimensional stability of the board. Apparently high resin content (at least 12%) was required to bond EFB fibres and produce boards of high mechanical properties and great dimensional stability.

Key words: Empty fruit bunches, mechanical properties, dimensional stability, fibre treatment, resin

INTRODUCTION

The wood composite industry is facing with serious shortage of forest resources and showing increased interest in production of lignocellulose based composites from other materials. The biggest alternative is agricultural residues (Guntekin *et al*., 2008). Natural fibres generated from agricultural residues such as palm oil, rice husks and pineapple leaf are particularly important natural resources in the wood-based industries. These natural fibres possess low density, low production costs, easy processing, light weight and low abrasiveness to equipment (Hill and Abdul Khalil, 2000). Such characteristics make these fibres remarkably viable for bio-composite production. Oil Palm Empty Fruit Bunches (OPEFB) is one of the major biomass types generated in the Malaysian oil palm industry. From 85.71 million tones of Fresh Fruit Bunches (FFB) produced in 2009, an estimated amount of 6.76 million tones of dried EFB was generated from oil palm mills (Kassim *et al*., 2011). Among the various oil palm fibre sources available, EFB has a potential to yield up to 73% fibres (Wirjosentono *et al*., 2004) and becomes the preferred material for the bio-composite industry based on its high availability and low cost (Rozman *et al*., 2000). Particularly the cellulose content (Sreekala *et al*., 2004) and high toughness (John *et al*., 2008) of OPEFB make it suitable for composite applications.

Many studies have reported results of incorporating EFB into composite products. However, some researcher (Paridah and Harmaen, 2003) have claimed that MDF made from oil palm EFB had much inferior properties compare to those made from rubberwood and other oil palm fibres. Chipboard made from this material, however, has comparable properties to those manufactured from rubberwood, except for machining properties (Ratnasingam *et al*., 2007). Because of the oil traces in the fibres, MDF produced from EFB has lower wettability, thus is more difficult to be glued or finished as reported by Paridah *et al*. (2000). Nevertheless, compare to MDF, it is more difficult to bond EFB fibres for particleboard manufacture due to lack of adhesive penetration as the results of the presence of residual oil and remnants of epidermis layer on the particles as reported in both studied by Paridah and Zaidon (2000) and Nor Yuziah *et al*. (1997). Generally, oil palm fibres contain 4.5% of residual oil (Bakar *et al*., 2006). It is reported that oil residues on the EFB fibres are still present even after

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oil extraction process in the factory. This may explain why many studies have reported similar poor board performance both for particleboards and MDF. Within this context, the control limit for the oil content of EFB fibres shall not exceed 3% to be suitable for production of down-stream products as stated in Malaysian Standard (Bakar *et al*., 2006).

Several workers on their studies have extracted EFB fibre with toluene, acetone and ethanol to reduce the residual oil in order to improve the bonding properties (Rozman *et al*., 2001; Bakar *et al*., 2006). Ramli *et al*. (2002) have carried out study on pre-treatment EFB fibre with sodium hydroxide (NaOH) and water to remove the residual oil. Based on the study, it is reported that the residual oil in EFB fibre is significantly removed by pre-treatment with NaOH rather than water. However, (Yusoff *et al*., 2009) reported that alkali treated fibre generates poor fibre with high bulk density, thus passively affecting the physical properties of the fibre. Alternatively, physical treatments, e.g., boiling in hot water, may provide a better solution. Although some researchers have concluded that the presence of residual oil in EFB fibre effect on bonding and finished properties in MDF (Paridah *et al*., 2000; Nor Yuziah *et al*., 1997) and weakened the end-products (Kobayashi *et al*., 1985; Ramli *et al*., 2002), study on the effect of removing the residual oil content in EFB fibres on board properties is still very limited. This study evaluates the effects of various treatments of EFB fibres on the properties of the MDF which these fibres produce. The mechanical properties and dimensional stability values of these boards are evaluated as well.

MATERIALS AND METHODS

Pre-treatment of EFB fibres: The EFBs in fibre form were obtained from Sri Langat Palm Oil Mill in Dengkil, Selangor (Malaysia). The EFB fibres were then sent to the Malaysian Palm Oil Board (MPOB) in Bangi (Selangor, Malaysia) for refining using a thermomechanical pulping process. The refined fibres were screened to 0.5-2.0 mm mesh size and then dried to <5% Moisture Content (MC). Afterwards, the dried EFB fibres were subjected to different treatments as shown in Table 1. All the treated fibres were re-dried to <5% moisture content prior to manufacturing the MDF.

Table 1: The EFB fibre pre-treatment methods

Treatment	Description
Untreated	Untreated fibre
Soaking	Fibres were soaked in 2% sodium hydroxide (NaOH) for 30 min
Boiling	Fibres were boiled in hot water for 30 min
Soaking and boiling	Fibres were soaked in 2% NaOH and then boiled in hot water for 30 min

Preparation of medium density fiberboard: The MDFs were manufactured in the Biomass Laboratory of the Malaysian Palm Oil Board (MPOB) at Bangi (Malaysia). The dried fibres, both treated and untreated, were blended with UF resin in a rotating drum-type mixer fitted with a pneumatic spray gun. Based on oven-dry particle weight, the UF resin was applied to the fibers at three percentages: 8, 10 and 12%. The blended fibres were then distributed manually in a wooden mould through a wire mesh. The hand-formed mats were then cold-pressed. Afterwards, these mats were hot-pressed at 175°C for 5 min under a press pressure of 160 kg cm^{-3}. Twelve boards of the dimensions 300×300×12 mm and target density of 750 kg m^{-3} were manufactured. The samples were conditioned in a chamber at 20°C and a relative humidity of 65+2% for a week.

Mechanical properties: After conditioning, the test samples were cut and the strength properties and Internal Bonding (IB) strength were determined according to MS Standards 1787: 2005. A total of 108 specimens were used in these tests.

A static bending test was performed on 250×50×12 mm specimens using an Instron Universal Testing Machine. Both the Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) values were calculated. The IB strength was determined by the tensile perpendicular to surface test using specimens of size 50×50×12 mm. The density and moisture content of the specimens were determined using samples cut from the remnants of the static bending test specimens.

Dimensional stability testing: The Thickness Swelling (TS) and Water Absorption (WA) were determined by measuring the thickness and weight of the specimens before and after immersing in distilled water at room temperature (25°C) for 24 h. The water absorption and thickness swelling percentages were calculated using MS 1787: 2005 (Anonymous, 2005):

$$\text{Water absorption (\%)} = \frac{W_n - W_d}{W_d}$$

where, W_n is the weight of composites samples after immersion and W_d is the weight of the composite samples before immersion:

$$\text{Thickness swelling (\%)} = \frac{T_1 - T_0}{T_0}$$

where, T_1 is the thickness after soaking and T_0 is the thickness before soaking.

Statistical analysis: Data for each test were statistically analyzed. The effects of fibre treatments and resin content on the panel's properties were evaluated by Analysis Of Variance (ANOVA) using the Statistical Analysis Software (SAS). The Least Significant Difference (LSD) method was used to identify the dominant factors and their interactions at the .05 level of significance ($\alpha = 0.05$). This method ranks the treatment group means by denoting different letters (a, b, c and etc.) to the factors and groups to mark significance and calculates the least significant difference that occurs between the group means. Means followed by the same letters are not significantly different at $\alpha = 0.05$, i.e., $p \leq 0.05$.

RESULTS AND DISCUSSION

The ANOVA results Table 2 show that there is significant interaction effect between the treatment types and resin levels, both on the mechanical properties and dimensional stability values of the EFB-MDFs. This implies that both factors; treatment and resin level, are synergistically affecting the board properties. Hence, the following discussions are based on these interactions.

Mechanical and bonding properties: The findings related to the average strength (MOR), stiffness (MOE) and Internal Bonding (IB) strength of the MDF produced from EFB fibres bonded with different levels of UF resin are summarized in Table 3. These findings demonstrate that there were improvements in all tested properties as the resin level was increased from 8 to 12%. Generally, the MOE manifested the highest improvement (>40%). These results were expected and are in line with the results of some previous studies (Woodson, 1976; Chow and Zhao, 1992; Ashori and Nourbakhsh, 2008). Similar observations on the relationship between resin content and strength properties were also reported by other researchers on wood (Moslemi, 1974), bamboo (Chen *et al*., 1991) and oil palm fibres. At high resin content, further bonding sites are available, thus improving the strength properties. Boiling of the EFB fibres prior to board making significantly enhanced the properties of MDF over those of the untreated EFB fibers. The MOR and MOE of the MDF produced in this study ranged from 13.4-33.4 and 1183-2838 N mm^{-2}, respectively. The inherent fibre quality of the Empty Fruit Bunches (EFB) itself poses several challenges in producing particleboard with acceptable working properties as reported previously by Ratnasingam *et al*. (2008a,b). Soaking the EFB fibres in NaOH reduced the strength properties of the board. Among the four types of treatment, boiling in water for 30 min. had brought about only slight increment in the EFB board properties examined even at the lowest resin level (8%).

The significant improvements in the mechanical properties of the MDF made from boiled fibre may be attributed to the increase in the extent of crystallinity and reduction of amorphous regions during the boiling treatment. A study by Inoue and Norimoto (1991) revealed that heating of wood under pressure had resulted in an increase in cellulose crystallinity. As the strength of wood also depends on the proportion of crystalline and amorphous regions (Hon and Shiraishi, 2001), the mechanical properties of fibres increase as the portion of crystallinity increases. In other respects, Tjeerdsma *et al*. (1998) suggested that during heating of wood both the

Table 2: Analysis of variance (ANOVA) for differences between EFB treatment effects on the mechanical, bonding and dimensional stability properties of the produced MDF

		p-value				
Source of variation	df	MOR	MOE	IB	WA	TS
Treatment (T)	3	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***
Resin Level (R)	2	0.0001***	0.0001***	0.0001***	0.0001***	0.0001***
T×R	6	0.0001***	0.0001***	0.005**	0.019**	0.0001***

**Significant difference at p<0.05, ***Significant difference at p<0.01, MOR: Strength, MOE: Stiffness, IB: Internal bleeding, WA: Water absorption, TS: Thickness swelling

Table 3: Mechanical and bonding properties of the MDF's manufactured from EFB fibres at different resin levels and under different treatment methods

	MOR (%)			MOE (%)			IB (%)		
	8	10	12	8	10	12	8	10	12
Treatments	(N mm^{-2})								
Untreated (UT)	22.3±2.3^{e}	27.9±2.2^{c}	31.4±2.6^{b}	1183±108^{h}	2241±113^{c}	2583±112^{b}	0.25±0.04^{f}	0.35±0.11^{e}	0.38±0.05^{d}
Boiling (B)	23.2±1.6^{e}	28.0±1.7^{c}	33.4±1.7^{a}	1939±115^{d}	2190±109^{c}	2838±108^{a}	0.43±0.08^{d}	0.63±0.11^{b}	0.87±0.13^{a}
NaOH (S)	19.7±1.8^{f}	23.6±1.5^{e}	26.21±0.5^{d}	1711±128^{e}	1962±104^{d}	2279±110^{c}	0.39±0.07^{e}	0.50±0.07^{c}	0.57±0.09^{b}
NaOH+boiling (SB)	13.4±1.2^{h}	16.2±1.4^{g}	17.2±1.2^{g}	1302±113^{g}	1486±127^{f}	1586±134^{f}	0.35±0.08^{e}	0.47±0.05^{c}	0.51±0.07^{c}

Values are Mean±SD of 27 specimens, For each property, Means with the same letters are not significantly different at $\alpha = 0.05$, MOR: Strength, MOE: Stiffness, IB: Internal bleeding hemicelluloses and lignin would first soften, flow and then cross-link to form strong network with cellulose. The increases in the portions of crystalline regions and formation of new, strong networks explain why the heated woods are normally stronger than the untreated ones.

On the other hand, significant reductions in both MOR and MOE were exhibited by the MDF produced from the EFB fibres that have been soaked in NaOH for 30 min. Treatment with NaOH induces some hydrolysis whereby varying proportions of the highly crystalline regions would be destroyed, therefore leading to an increase in the proportion of amorphous regions (Browning, 1967). As a result, the cellulose becomes more accessible which makes the fibre more flexible than before and tending to agglomerate and form lumps. Upon hot pressing the lumps would be pressed into much dense spots relative to the rest of the board. Such uniformity creates additional internal stress, particularly in bending which consequently lowers the MOR and MOE values of the board. Soaking in NaOH and boiling affected the most severe effects on the board's MOR and MOE. During alkali treatment (soaking) for 30 min at high temperatures (100°C), the potential for hydrolysis is quite high. In consequence, many of the soaking-treated fibres become shorter and more flexible than the untreated ones. On the other hand, it seems that during fibre refining substantial fibrillation took place, hence generating much finer fibres and higher fiber total surface area than before refining. Accordingly, the increased surface area would need high amount of resin which itself results in a poor strength (Bekhta and Hiziroglu, 2002). Furthermore, the discontinuous fibres generated from fines also prevent stress transfer in the MDF (Malonney, 1993).

The IB strength indicates homogeneity of adhesion between the fibres. As can be seen in Table 3, the IB strength of the MDF produced from boiling-treated fibre increased as the resin level increased beyond the minimum requirement for the production process as stated in the MS Standard 1787: 2005. This indicates that pre-boiling of the EFB fibres in presence of a sufficient amount of resin would give a relatively greater IB strength than what can be obtained using the untreated fibres. One of the potential explanations why the MDF manufactured from boiling-treated fibres exhibited higher IB than the IB values demonstrated by the MDF generated from the fibers under the other treatments can be that more fibres matted up together under the former treatment than under any of the latter, thus creating more fibre to fibre contact and glue line contact under the former treatment than under any of the latter (Hunt and Vick, 1999). This is expected finding in view of the increased bonding between the fibres and the enhanced resin efficiency during hot pressing. Similar results have been supported by previous studies (Nemli *et al*., 2007).

Pre-boiling the EFB fibre has some apparent effects on the bonding strength of the boards. For example, boiling removes the wax and pectin from the fibre surfaces which consequently improves the wettability of the fiber. According to Lee *et al*. (2004), wax and pectin influence the bonding properties of boards. The wax is primarily located in the cuticle and primary wall of fibre. However, small amounts of residual wax may form a thin film on the fibre surfaces. Lawther *et al*. (1996) reported that steam treatment removed some portions of pectin substances and hemicelluloses from wheat straw. The pectin substances and high content of hemicelluloses in non-woody lignocellulosic materials usually result in limited adhesion between resin adhesives and these materials. Based on findings by Munawar *et al*. (2007), the surfaces of steam-treated fibers are smoother than those of untreated fibres. This is due to removal of some materials (e.g., wax and pectin) from the fibre surfaces which allows the resin to spread quite easily on these surfaces. So, removal of these substances contributes to enhancement of board properties.

Dimensional stability: Thickness Swelling (TS) of a wood panel composite refers to the swelling in the thickness direction of the panel as a result of exposure to water for a certain period of time. Exposure, however, involves only the surface of the panel. The hydrophilic properties of lignocellulosic materials and the capillary action induce intake of water during soaking and thus increase the TS and Water Absorption (WA) of the panel. Thickness swelling is normally related to the inter-particle/fibre bonding. A good bonding would result in low TS and vice versa. The low IB values indicate that the fibres were not effectively bonded together hence cannot prevent the water from penetrating into the fibres (Zaidon *et al*., 2007). The WA, on the other hand, depends mainly on the affinity of the fibres to water and hence does not rely much on the bonding strength. As Table 4 illustrates, generally all the treatments improved the dimensional stability of the boards over that of the boards produced from the untreated fiber. It was observed that swelling of the boards made from boiled fibres was the lowest (24.1-14.8%). Swelling of the untreated boards fell in the range of 30-22%. It was noted also that when the percentage of resin increased, the TS and WA of the MDF decreased significantly (Table 4) and that reductions in the values of TS were about the same in all types of board.

For instance, the boiling treatment improved the TS from 24.1-14.8% when the resin content was increased

Table 4: Water absorption (WA) and thickness swelling (TS) values of the MDF's manufactured from EFB fibres at different resin levels and under different treatment methods

	WA (%)			TS (%)		
	8	10	12	8	10	12
Treatment	(N mm^{-2})					
Untreated (UT)	88.3±5.1^{a}	76.3±4.9^{c}	63.9±4.7^{e}	30.9±1.7^{a}	24.9±1.1^{d}	22.0±1.5^{f}
Boiling (B)	73.2±2.1^{c}	56.7±2.9^{g}	51.0±2.8^{h}	24.1±1.7	16.9±1.9^{j}	14.8±1.5^{k}
NaOH (S)	83.1±4.6^{b}	72.2±4.8^{d}	61.4±4.0^{f}	29.7±1.5	22.9±1.2^{f}	18.0±1.3^{i}
NaOH+boiling (SB)	80.3±4.3^{b}	65.0±4.9^{e}	60.5±4.2^{f}	28.4±1.6	21.1±1.2^{g}	18.7±1.3^{h}

Values are Mean±SD of 108 specimens, For each property, means with the same letter are not significantly different at $\alpha = 0.05$

from 8-12%. In the case of the NaOH treatment, the TS improved from 29.7-18.0% and from 28.4-18.7% under both the soaking and boiling treatment. The reduction of the TS may be related to degradation of hemicelluloses and lignin in the fibre during the boiling treatment. This explanation was earlier supported by Tjeerdsma and Militz (2005) who highlighted that the hemicelluloses degraded due to thermal elevation and that it in consequence transformed into soluble extractives. As the hemicelluloses in the cell walls are very hydrophilic compounds, their removal can affect the dimensional stability of the boards. The hemicelluloses are heteropolymers with branched structures which have high tendencies for water absorption. Any removal of the hemicelluloses can influence the board swelling significantly. The increase in the proportions of crystalline regions in the cellulose microfibrils may be another reason behind the marked reduction in TS (Yildiz and Gumuskaya, 2007), presumably due to that after the boiling treatment less hydroxyl groups are free in the cellulose microfibrils than before this treatment.

The alkali treatment can reduce the hydroxyl groups in the cell walls of natural fibre molecules and this may therefore be responsible for the decrease in water absorption by the composites. However, it is interesting to note that boards produced from NaOH-soaked fibres had relatively higher TS values than boards manufactured from boards treated by boiling alone. This may be attributed to the fact that the residual oil in the EFB fibres which forms a thin film on the fibre surfaces and prevent water from penetrating the board, have been effectively removed by the alkali treatment. It was also observed that the presence of lumps in the alkali-treated board had some effects on the TS. These lumps require additional force to deform during hot press and as a result extra stresses were created in the conventional composite. When the composite was exposed to water, a great proportion of these stresses was released and caused a pronounced reversal of densification which in turn lead to high TS (Abdul Khalil *et al*., 2008). In addition to this phenomenon, the hydrophilic nature of EFB having cellulose and lignin containing free hydroxyl group make these fibre absorb water easily through hydrogen bonding in the fibre cell wall (Karina *et al*., 2008).

As in mechanical properties, boards manufactured using higher resin content generally result in better dimensional stability characteristics with profoundly lower TS and WA than boards produced using lower resin content. It was particularly noticeable that the high resin level has remarkable influence on the TS properties. These results are in agreement with other research on natural fiber polymer composites (Youngquist *et al*., 1992; Krzysik *et al*., 1993). Furthermore, the WA significantly decreases with increased resin content due to the greater fibre bonding strength which the additional resin brings about over the lower resin content. This observation is consistent with findings by Nugroho and Ando (2000) who concluded that higher resin levels could enhance the inter-fibre bonding and reduce the void spaces, thus resulting in lower WA. Tangjuank and Kumfu (2011) also concluded that in board manufactured using high resin content, the binder is cured more effectively in the void spaces of the board and there is less water absorption.

CONCLUSIONS

This study revealed that it is possible to produce MDF from oil palm EFB fibre. Among the treatments, boiling was the EFB fibre treatment conducive to the best properties for the realizable MDF when the UF resin was employed. In this case, the MDF produced from EFB fibres after a boiling treatment using resin at the level of 12% lead to significant improvement in all the board properties. Overall, the board performance also improved significantly with the highest resin level. This finding leads to the conclusion that using high amounts of resin will improve the mechanical and dimensional stability properties of the board.

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