Journal of Applied Sciences

ISSN 1812-5654

science alert

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Journal of Applied Sciences 12 (6): 575-580, 2012
ISSN 1812-5654 / DOI: 10.3923/jas.2012.575.580

Influence of Thermo Mechanical Pulping Production Parameters on Properties of Medium Density Fibreboard Made from Kenaf Bast

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Abstract: The objective of this investigation was to evaluate different Thermo-Mechanical Pulping (TMP) conditions on the properties of Medium Density Fibreboard (MDF) made from kenaf bast. Experimental panels with a target density of 700 kg m^{-3} were manufactured from raw material produced using different pressure levels of 3, 5 and 7 bar at two refining times, namely 3 and 5 min employing TMP process. The fibres were blended with 12% urea formaldehyde resin. The Water Absorption (WA), Thickness Swelling (TS), Modulus of Rupture (MOR), Modulus Of Elasticity (MOE) and Internal Bonding (IB) of the panels were determined based on Malaysian Standard 1787: 2005. The study indicated that refining pressure had a dominant affect on overall board properties in an exception of their water absorption property. Refining time however, had no effect on both fibre and most of the board properties. Internal bonding values of the samples enhanced with extended refining time of the fibres. The results also showed that fibre morphology had some influence on the final board properties. Longer fibre produced board with relatively lower water absorption and thickness swelling, but higher in modulus of rupture and internal bonding values.

Key words: Refining pressure, refining time, kenaf bast, medium density fibreboard, physical and mechanical properties

INTRODUCTION

The composite industry is facing shortage of wood resource and tends to utilize lesser known wood and others lignocellulosic sources as main raw materials (Loh *et al*., 2010 ; Akgul *et al*., 2007; Guntekin *et al*., 2008; Halvarsson *et al*., 2009; Kargarfard and Latibari, 2011; Suradi *et al*., 2010). There are many lignocellulosic fibres that have been explored as a main raw material and kenaf (*Hibiscus cannabinus* L.) is considered potential sources for composite industry. Based on H'ng *et al*. (2009), almost seventeen varieties of kenaf are introduced and nine kenaf varieties were identified as potential to be planted commercially in Malaysia. Recently, kenaf have been used as a material for pulp and paper industry (Olotuah, 2006), particleboard (Juliana *et al*., 2012; Izran *et al*., 2009), fibreboard (Xu *et al*., 2006) and polymer composite (Karina *et al*., 2007; Khalina *et al*., 2008).

Kenaf is fast growing plant and could be harvested in just 4 to 5 months with the height about 4.68 m (Maqsudul Alam *et al*., 2001). Kenaf consists of two major parts that are distinctly different, bast and core. The outer bark so called bast is about 35-40% and the inner woody core is 60-65% of the total of stem weight (Abdul-Khalil and Suraya, 2011). Length of fibre from the bast area is about 3.6 mm which is similar to that of typical softwood fibre. However, fibres from the core portion of kenaf are shorter with an average length of 1.1 mm similar to hardwood fibres (Abdul-Khalil *et al*., 2010) with density of about 0.1 g cm^{-3} (Tahir *et al*., 2011). These two parts of

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fibre are greatly different from each other in terms of their fibre morphology and chemical composition, therefore they are not recommended to be pulped and refined together (Ohtani *et al*., 2001).

Previous studies have concluded that the properties of kenaf fibres such as morphology, fibre acidity, bulk density, fibre distribution and fibre moisture content influenced the performance of MDF panels (Suchsland and Woodson, 1991; Xing *et al*., 2006a; Xu *et al*., 2006). One of the factors that affect the fibre properties is refining process which is an important parameter for effective of MDF production. Refining is referred processing of the fibres by applying friction between two rotary discs opposite to each others so that fibres are compressed and decompressed resulting in modification of their geometry. In MDF industry, Thermo-Mechanical Pulping (TMP) process is commonly used to refine fibres by application of pressure and temperature (Sabharwal *et al*., 1995). In typical TMP process, refining pressure and time are the two main manufacturing parameters that fibre geometry which consequently will influence almost all properties of the MDF panel product.

A study by Overend and Chornet (1987) noted that during TMP, the steaming and refining process would separate raw materials into individual fibres and bundles. There are two different mechanism involved during this stage. First, the soften fibres due to steaming and their disintegration into either single or small fibre bundles. Second, those fibres are further refined to have ideal geometry with required properties.

It is a well known fact that fibre aspect ratio influence almost all properties of the final products. Fibre length has a strong effect on dimensional stability of fibreboard because longer and thinner fibres improve thickness swelling and linear expansion properties of fibreboard. Furthermore, the amount of overlap between fibres will also play an important role to develop good bonding among them (Malonney, 1993).

Currently there is little information related to evaluate effect of refining on panels made from kenaf bast fibres. Therefore, the objectives of this study was to determine the physical and mechanical properties of MDF panels made from kenaf bast as a function of fibre geometry and refining condition to provide initial data.

MATERIALS AND METHODS

Raw material production and panel manufacture: The raw material for the experimental was obtained from kenaf plantation in Pasir Putih, Kelantan, Malaysia. Five-month-old kenaf stem were harvested manually. The Moisture Content (MC) of green stem was about 120-140 %. The stem consists of bast and core, thus they were separated from each other by peeling. The long bast parts were cut into 10-15 cm long sections and then they were refined using thermo-mechanical pulping. The pressurized refiner is equipped with a 30 cm diameter refiner disc, running at variable speeds that can reach up to 5000 rpm. Three refining pressures i.e., 3, 5 and 7 bar, having three different temperature namely 140, 160 and 180°C, respectively and two refining times i.e., 3 and 5 min were used to produce the raw material. The refined fibres were then dried in the oven to have MC of 4-5%. Random samples of fibre bundle from each refining condition were collected. The geometry of the fibre were analysed and measured using an image analyzer (Model Quantiment 520 with Leica Camera Model MPS32). From each refining conditions, the length and width of 100 fibres were randomly measured. The aspect ratio, the length-to-width ratio of each fibre was also calculated.

Specific amount of fibres were weighed and placed in a rotary drum blender equipped with a pressurized spray nozzle. Urea Formaldehyde (UF) resin with 65% solid content was sprayed onto the fibres until the entire adhesive and the fibre were blended uniformly. The UF resin content was fixed at 12% of oven dry weight of the fibres. The furnish was then collected and placed in a 300×300 mm size template and formed manually into a mat. Initially the mats were cold pressed followed by hot pressed at pressure of 160 kg cm^{-2} and a temperature of 175°C for 5 min into 10 mm thick board by employing a computer controlled press. The target density of the board was 700 kg m^{-3}. A total of 24 panels, four panels were manufactured for each refining conditions. The boards were conditioned at a temperature of 23±2°C with a relative humidity of 65±2% for a week until the panels reached equilibrium moisture content before any tests were carried out.

Evaluation of panel properties: The mechanical properties of the boards were tested using an Instron Testing Unit according to the Malaysian Standard, MS 1787: 2005 (Anonymous, 2005). A total of 96 specimens were tested for static bending and internal bonding. The specimens for static bending test were 200×50×10 mm in size while those for Internal Bonding (IB) were 50×50 ×10 mm in size. Three-point static bending test was conducted over a span of 200 mm. The crosshead speed of 10 mm min^{-1} was used. Samples were glued to the metal blocks with a hot melt adhesive for IB test using and Instron Testing Unit at crosshead speed of 0.7 mm min^{-1}.

The physical properties of the boards were also tested according to Malaysian Standard, MS 1787:2005

(Anonymous, 2005). Four test specimens with 50×50 mm in size were prepared from each sample board for TS and WA characterization of the panels. The WA of the sample were determined by measuring the weight of the sample before and after immersed in distilled water at room temperature for 24 h. The TS was determined by measuring the thickness of the sample before and after immersion in distilled water.

Statistical analysis: The data were statistically analyzed using Statistical Analysis System (SAS) software. An analysis of Variance (ANOVA) was used to examine the effects of each refining condition on the properties of the panels. The Least Significant Difference (LSD) method was used for mean separation to further evaluate the effects of refining pressure and refining time and also the interaction between both factors. This method calculates the least difference that should occur between two means and compare then at value of $p \leq 0.05$.

RESULTS AND DISCUSSION

Effects of refining conditions on the fibre geometry: The average values of fibre length, width and aspect ratio are presented in Table 1. In general, fibre length reduced with increasing refining pressure and time. However, reduction in fibre length was not significant in the case of 3 and 5 min refining time periods. Also, in the case of fibres refined using 5 bar and 3 and 5 min refining time did not agree above finding. No clear conclusive explanation was found for these findings. Also, shown in Table 1, similar effects were observed for aspect ratio at lower refining pressure less than 5 bar, the effects of refining time were also more prominent.

Table 2 displays the result of the analysis of variance (ANOVA) on the fibre properties. There were significant interactions (at $p \leq 0.05$) between pressure and time on the fibre length and aspect ratio. Fibre width however was not significantly affected by any of the variables.

Sundholm (1999) and Karnis (1994) stated that softening of fibres is a very important factor in order to preserve fibre length and also to develop high quality fibre with better bonding ability. The degree of fibre softening and fibrillation depends on the refining pressure, temperature and time of the steaming, which determines the fibre aspect ratio which is ratio between fibre length and fibre width. At higher pressures, the refining may lead to harsh mechanical action/higher refining intensity due to the reduction in the plate gap.

A study by Belini *et al.* (2008) on the effect of refining conditions showed that except for fibre width, fibre length, cell wall thickness and lumen diameter of *Eucalyptus* spp, were affected by refining pressure, temperature and time. They also found that these variables had significant influence on the aspect ratio. Rowell *et al.* (2000) stated that aspect ratio indicates the potential strength properties of a board since it influence the interfibre bonding and the strength of the resulting board.

According to Xing *et al.* (2006b), during refining process, pressure plays very important role on the quality of fibres which later influence the performance of final product. Krug and Kehr (2001) suggested that increasing the refining pressure and time reduced the fibre length resulting in larger percentage of broken fibres.

Effects of refining conditions on the mechanical and physical properties of MDF: Table 3 shows test results of the panels for the effects of refining conditions on properties of the panels, respectively. Compared to fibre geometry, the panels properties were much more affected by refining conditions.

The results of analysis of variance (ANOVA) are shown in Table 4. Significant interactions between pressure and time were observed for all board properties including MOR, MOE, IB and TS except for WA. As indicated by the significance level, WA was only slightly influenced ($p \leq 0.10$) by refining time. The ideal refining combination is also identified.

As displayed in Table 3, both, the MOR and MOE of the samples were decreased with increasing refining pressure. Extending the refining time had mix effects on these properties. Almost all MOR and MOE of the samples were improved slightly as the refining time was increased from 3 to 5 min Krug and Kehr (2001) and

Table 1: The mean value of fibre length and aspect ratio from various refining conditions

Refining pressure (bar)	Refining time (min)	Fibre length (mm)	Fibre width (mm)	Aspect ratio
3	3	1.67±0.005^{a}	0.026±0.0002^{a}	61.44±2.77^{b}
	5	1.22±0.002^{b}	0.027±0.0002^{a}	45.90±2.56^{d}
5	3	1.42±0.001^{a}	0.026±0.0004^{a}	54.73±2.22^{c}
	5	1.69±0.001^{a}	0.025±0.0004^{a}	67.49±1.82^{a}
7	3	1.60±0.002^{a}	0.025±0.0010^{a}	64.04±3.25^{a}
	5	1.59±0.002^{a}	0.024±0.0009^{a}	64.66±2.09^{a}

Means followed by the same letters in each column are not significantly different at $p \leq 0.05$

Table 2: Summary of ANOVA on the fibre properties

		p-value		
Effects	df	Length	Width	Aspect ratio
Refining pressure	3	ns	ns	**
Refining time	2	ns	ns	***
refining pressure ×refining time	6	**	ns	**

**Significantly different at $p \leq 0.05$, ***Significantly different at $p \leq 0.01$, ns: Not significant

Table 3: Interaction effects of refining pressure and time on board properties

Refining pressure (bar)	Refining time (min)	Modulus of rupture (MPa)	Modulus of elasticity (MPa)	Internal bonding (MPa)	Thickness swelling 24 h	Water absorption 24 h
3	3	23.39±1.91[a]	2046±192.58[a]	0.15±0.17[b]	26.25±1.01[b]	78.39±5.21[a]
	5	22.48±2.98[a]	1932±166.07[b]	0.26±0.05[a]	26.85±1.26[b]	78.34±5.29[a]
5	3	19.83±1.93[c]	1721±161.89[c]	0.28±0.06[a]	25.92±1.62[c]	76.77±6.05[a]
	5	21.16±1.51[b]	1830±159.15[c]	0.30±0.11[a]	25.47±1.66[c]	74.10±6.04[b]
7	3	20.59±2.32[b]	1921±274.53[b]	0.24±0.06[a]	28.77±1.17[a]	77.90±6.54[a]
	5	22.94±2.52[a]	2113±275.21[a]	0.17±0.12[b]	27.06±1.29[b]	73.89±5.70[b]

Means followed by the same letters in each column are not significantly different at $p \leq 0.05$

Roffael *et al.* (2001) stated that increasing the steam pressure resulted in lower MOR and MOE values of the panels due to the reduction of fibre strength in spite having longer fibre and aspect ratio. On the order hand, Labosky *et al.* (1993) reported contradicted results where increasing steam pressure did not have significant effect to the MDF properties.

Modulus of rupture values of the samples had significant increase with increasing fibre length. This could be related to having high percent of fibres in board resulting in larger surface contact area and improving the fibre to fibre bond, consequently resulted in higher MOR value of the samples. This is consistent with the results of a study by Nourbakhsh and Ashori (2009) who stated that one of the most important parameters controlling the mechanical properties in composites is having long fibres with high aspect ratio.

The highest MOE found for boards refined using a pressure of 7 bar for 5 min which recorded value of 2113 MPa. Sundqvist *et al.* (2006) associated this effect to the formation of formic acid and acetic acid from the hemicelluloses degradation as a result of heat and pressure during refining. As refining temperature is increased such effects was more prominent. The high concentration of these types of acids may have some effects on the fibre length due to cellulose degradation, to some extent influenced the strength board. It was also noted that the prolonged heating could made the flexible fibres since lignin starts to soften and flow at temperature more than 150°C. Therefore, the stiffness of the board increased resulting in higher MOE values of the samples.

A high aspect ratio is desirable to have better panel properties in any wood composite products (Rowell *et al.*, 2000). Stark and Rowlands (2003) also reported that aspect ratio, rather than particle size, has the greatest effect on strength and stiffness of the panel. This is consistent with the findings of a past study stated that one of the most important parameters controlling the mechanical properties of short fibres composite is the fibre length or more precisely its aspect ratio (Nourbakhsh and Ashori, 2009).

The mean value of IB under different refining condition are shown in Table 3. The IB value increased with an increasing in pressure and time. According to Xing *et al.* (2007) and Shen (1991), the IB of MDF increased with increasing refining pressure through the conversion of hemicellulose component into low molecular weight water-soluble carbohydrates that act as a binder. However, when too much pressure being applied, the lignin starts to melt and flow interrupting the bonding between the fibres resulting in a poor IB value. The highest IB value of 0.30 MPa, were determined for the board using a pressure of 5 bar and for 5 min refining time. It seems that fibre length is the dominant factor affecting the overall IB values of the panels. This is also supported by a study from Suchsland and Woodson (1991) found that as the length of overlapping fibres is shortened, the quality of the bond between fibres is reduced.

On the other hand, kenaf bast is difficult to bond as compared to kenaf core and rubberwood (Paridah *et al.*, 2009). Relatively, low IB values ranging from 0.11 to 0.30 MPa were determined. These values generally met the minimum requirement of 0.2 MPa by the Malaysian standard.

Comparison of the board properties as affected by different combination of refining pressure and time are shown in Table 3. The WA was significantly different when raw material refined at a pressure of 5 bar and 5 min and indicated that there was a reduction on the WA as the refining time was increased to 5 min, improved from 78.39 to 73.89%. At longer time, the heat would be sufficiently high to soften the lignin at the middle lamella. Heat causes softening of the lignin in the middle lamella which longer refining time resulting in more disintegration of fibre water absorption values of the samples.

Significantly higher TS was found in the board made from fibres that were refined at pressure of 7 bar. Apparently changing the pressure from 3 to 5 bar and 7 bar reduced the TS more significantly than changing the time from 3 to 5 min. The lowest TS value of 25.47% was found for panels made using a pressure of 5 bar for either 3 or 5 min of refining times. Longer fibre have relatively higher board strength. This can be seen in the boards made using refined fibres at all pressures and 5 min refining which also by the longest as given in Table 2. The result of Malonney (1993) also support such finding

Table 4: Summary of ANOVA on the physical properties of MDF

		p-value				
Effects	df	MOR	MOE	IB	TS	WA
Refining pressure	3	***	***	***	***	ns
Refining time	2	*	ns	***	ns	*
Refining pressure ×refining time	6	**	**	***	**	ns

*Significantly different at p≤0.10, **Significantly different at p≤0.05, ***Significantly different at p≤0.01, ns: Not significant

that fibre length has a strong effect on the physical properties of fibreboards because longer and thinner fibres improved physical properties.

CONCLUSION

This study showed that it is possible to produce MDF from kenaf bast fibre using more severe refining conditions. Based on the results of this work, it is suggested that raw material should be refined at mild condition having 3 and 5 bar refining pressure or at severe refining condition by using 7 bar refining pressure. The result showed that refining pressure had a greater effect on fibre length and board properties compared to that of refining time. The findings also indicated that fibre length influenced overall board properties. Refining at a pressure of 5 bar and 5 min resulted in longer fibre length and boards with better physical properties, higher MOR and IB values. Meanwhile, the fibre formed using rather severe conditions produced boards with the highest MOE values.

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