Medium Density Fibreboard Made from Kenaf (*Hibiscus cannabinus* L.) Stem: Effect of Thermo-mechanical Refining and Resin Content

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The present study deals with the physical and mechanical properties of dry-formed medium density fibreboard (MDF) made from renewable biomass kenaf (*Hibiscus cannabinus* L.) stem as a function of adhesive level and refining conditions. Raw material was prepared by heating for 5 min at pressure levels of 6 and 8 bars. Experimental samples with a target density of 700 kgm^{-3} were produced with 10, 12, or 14% urea formaldehyde as a binder. Physical properties of MDF panels, such as thickness swelling (TS) and water absorption (WA) as well as mechanical properties including modulus of rupture (MOR), modulus of elasticity (MOE), and internal bonding (IB), were evaluated. Based on the test results, resin content and refining pressure have significant effects on the physical and mechanical properties of MDF panels. High resin content and pressure produced MDF boards with low WA and TS but high MOR, MOE, and IB. At 8 bars pressure and 14% resin content, the MDF recorded optimum WA (83.12%), TS (20.2%), MOR (25.3 MPa), MOE (3450 MPa), and IB (0.51 MPa).

Keywords: Kenaf fibre; Medium density fibreboard; Physical properties; Mechanical properties

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INTRODUCTION

Due to the current environmental situation, it is difficult for wood-based industries to obtain a continuous supply of wood from forests. Therefore, alternative materials for composite production are gaining interest among researchers (Abdul Khalil *et al.* 2010). Production of composite material from these diversified resources help to reduce the pressure on natural forests. Kenaf (*Hibiscus cannabinus* L.) is an herbaceous annual plant of the family Malvaceae that can be grown under a wide range of weather conditions. Kenaf is able to reach a height of 3 to 5 metres within 3 to 5 months and supplies between 12 and 25 t/ha of biomass annually when it is planted under warm and wet conditions (Paridah *et al.* 2011). Kenaf have been used in the pulp and paper industry (Olotuah 2006) for particleboard (Juliana *et al.* 2012), fibreboard (Xu *et al.* 2006), and polymer composites (Ibrahim 2010; Aji *et al.* 2011; Karina *et al.* 2007). The utilization of the stem bast fibers and core of kenaf for the production of composite boards has been developed worldwide (Ismail *et al.* 2010).

Lignocellulosic fibres, including kenaf, can be potential raw material for the manufacture of medium density fibreboard (MDF) (Juliana *et al.* 2012). MDF is a fibre composite material comprised of refined wood fibres, adhesive (resin), process additives, and a minor amount of wax. The strength of MDF depends on its fibres and the adhesive bonds between the fibres (Xing *et al.* 2006). MDF is manufactured by reconstituting fibres through a flexible and wide range of manufacturing conditions. The refining process is an important parameter for MDF production that affects fibre properties. Previous researchers reported that the properties of kenaf fibre influenced the performance of MDF panels (Xing *et al.* 2006). The thermo-mechanical pulping (TMP) process is commonly used in the MDF industry to refine fibres by application of pressure and temperature. In the typical TMP process, refining pressure and time are the two main manufacturing parameters that obviously affect the final properties of the MDF panel (Aisyah *et al.* 2012). Aisyah *et al.* (2012) reported that refining pressure affects overall MDF properties except water absorption property. However, refining time had no effect on the properties of fibre and board (Aisyah *et al.* 2012). Labosky *et al.* (1993) observed that an increase in resin content of the boards from 6 to 12% resulted in a significant increase in internal bonding (IB), modulus of rupture (MOR), and modulus of elasticity (MOE), whereas thickness swelling (TS) and water absorption (WA) properties decreased, but an increase in refining pressure did not significantly affect strength and dimensional stability (Aisyah *et al.* 2012). Krug and Kehr (2001) reported that increasing the steam pressure resulted in shorter fiber lengths, lower strength, and lower elastic properties but improved long-term swelling properties. Roffael *et al.* (2005) found that high pulping temperature resulted in lower TS and WA of MDF panels. The results from Deng *et al.* (2006) and Xing (2006) indicated that both MOE and MOR could be improved when refining steam pressure increases. Groom *et al.* (2004) studied the effects of varying refining pressure on the properties of refined fibers, and found that steam pressure caused some changes in the chemical composition of refined fibers. The difference in fiber characteristics generated by different refining plate patterns and specific energy may be another reason for the different results from different studies (Nayeri *et al.* 2013).

The study of potential usage of kenaf as partial or whole raw material for MDF and the effects of thermo-mechanical refining conditions on MDF panel properties have not been studied in detail. The objective of this work was to determine the effect of refining pressure and resin content on physical (WA and TS) and mechanical (MOE, MOR, IB) properties of dry-formed medium density fiberboards (MDF) made from renewable kenaf stem.

EXPERIMENTAL

Raw Material Preparation

Five-month-old kenaf (*H. cannabinus* L.) stem was obtained from the National Kenaf and Tobacco Board plantation located in Kelantan, Malaysia. After two weeks air-drying at room temperature, kenaf stems were chipped using a laboratory drum chipper. Then, the kenaf chips were refined using a thermo-mechanical pulping (TMP) refiner at the MDF pilot plant located at the UKM (Universiti Kebangsaan Malaysia) field station of the Malaysian Palm Oil Board (MPOB), Selangor, Malaysia. The Sprout-Bauer (Andritz, USA) TMP refiner is equipped with a 300-mm-diameter refiner plate and a plate gap of 0.36 mm, and it operates at variable speeds of approximately 4000 rpm. After refining, the fibre was discharged through the blow-line and dried in a flash tube dryer. No wax or resin was injected during refining. The target moisture content of the refined fibers, after tube drying, was about 20%. The kenaf chips were refined at two digestion pressures of 6 and 8 bars for 5 min of heating time. Fibres were then dried in an oven to achieve the moisture content (MC) of 4 to 5%.

Preparation of MDF Board

The refined fibers were dried up to a 4% moisture content in a traditional oven before resin blending. An amount (0.1%) of solid ammonium chloride (NH_4Cl) and water were mixed into conventional urea-formaldehyde adhesive (WC-10) with 65% solid content (before mixing). The diluted glue was sprayed onto fibres in a consistent manner using a mechanical rotary drum blender with an internal spray nozzle. The adhesive levels were set at 10%, 12%, and 14%, as expressed as a percentage of adhesive solid weight based on the oven-dried fibre weight. The resinated fibres were then manually formed into mats using a wooden frame. All the MDF mats were hot-pressed under the identical hot-pressing parameters of 180 °C for 5 min (Xing *et al.* 2007). After being conditioned at 22 °C and 65% relative humidity for two weeks, the boards were trimmed to 280 mm × 280 mm.

Characterization

The physical and mechanical properties of the MDF boards were tested according to JIS A 5905:2003 (Japanese Industrial Standard). Modifications were made to the size of the test specimen due to the small board size. The MDF properties determined were specific gravity (SG), MOE, MOR, IB, TS, and WA. The static bending test was performed on a universal testing machine to calculate MOE and MOR. The internal bond strength was determined by testing tensile strength perpendicular to surface. The soaking test was employed to obtain TS data by measuring the thickness of the sample before and after immersion in distilled water. The WA of the sample was determined by measuring the weight of the sample before and after immersed in distilled water at room temperature for 2, 12, and 24 h.

Vertical density profiles of each IB specimen before sanding and gluing were measured with a Laboratory Density Analyser DAX GreCon-US. The procedures of the tests are detailed in the JIS A 5905 (Japanese Industrial Standard). Multifactor analysis of variance of the test data was conducted in SAS System (SAS Institute Inc., Cary, NC).

Data analysis

The experimental design was a factorial arrangement of treatments conducted in a completely randomized repetition design with sampling. The outline of the experimental design is presented in Table 1. Eighteen treatments were formulated as:

Treatments = 3 adhesive levels × 2 TMP refining pressures × 3 replications

Three panels of MDF were produced under condition tabulated in Table 2. A total of 18 MDF samples were produced for this research. Analysis of variance (ANOVA) and mean separation using the least significant difference (LSD) method were carried out to evaluate the effect of thermo-mechanical refining pressure and resin level on physical and mechanical properties of MDF panels. The LSD calculates the difference between two means and compares it with the LSD value. If the difference is greater than the LSD value, the two means are denoted with different symbols (*, **, ***, *etc*.), implying that they are significantly different with each other at $p \leq 0.01$.

Table 1. Composition of the MDF Panels Indicating the Refining Pressure and Resin Content

Variables	Levels
Refiner pressure	6 (bar), 8 (bar)
Resin content	10%,12%,14%

Table 2. Lab Panel Manufacturing Parameters

Processing parameter	Value
Nominal density (kg/m^3)	700
UF resin content (%)	10,12,14
Panel dimension (mm)	300 × 300 × 12
Catalyst (NH_4Cl) content (%)	0.1 (solid basis on resin solid)
Press temperature (°C)	180
Total Press time (sec)	300

RESULTS AND DISCUSSION

Overall Mechanical and Physical Properties

A summary of the ANOVA of the MDF properties is given in Table 3, which shows that there was significant interaction ($p < 0.05$) between refining pressure and resin content on all the MDF properties.

Table 3. Summary of ANOVA on the Mechanical and Physical Properties of MDF Samples

		Significance Level				
Parameters	d.f	MOR	MOE	IB	WA	TS
Refining pressure	1	<.0001***	<.0001***	<.0001***	0.0384**	0.0818**
Resin content	2	<.0001***	<.0001***	<.0001***	<.0001***	<.0001***
Refining pressure × Resin content	2	0.0115**	0.0310**	1.0000 ns	<.0001***	<.0001***

Note: ns: not significant. d.f.: degrees of freedom
** Significantly different at $p < 0.05$.
*** Significantly different at $p < 0.01$

Effects of Refining Conditions and Resin Content on the Mechanical Properties of MDF Samples

Figure 1 shows the modulus of rupture results of kenaf particleboards fabricated using different resins content and pressure. MOR indicates the ability of a specimen to resist a transverse (bending) force perpendicular to its longitudinal axis. It can be observed from Fig. 1 that the mean MOR values increased with the increase of resin content and an increase in pressure to 8 bars. This indicates that the presence of resin has significantly affected the bending strength by reacting with water in the kenaf particles to create cross-linked polyureas for better mechanical bonding.

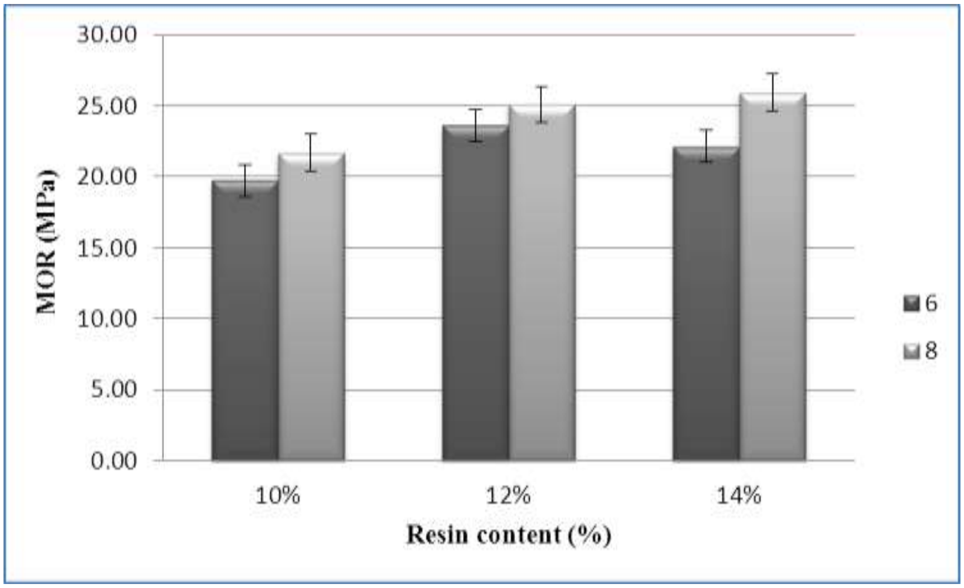

Fig. 1. Modulus of rupture of samples manufactured with different refining conditions (pressure 6 and 8 bar) and resin contents

MOE values of MDF board are illustrated in the Fig. 2. MOE is related to the stiffness of a board, with the higher the MOE of the board, the greater the board stiffness. Generally, boards tend to be more brittle when the MOE value is high and tend to be more ductile or flexible when the value is low.

From the mean MOE values presented in Fig. 2, it can be seen that the value increased as the resin content increased. This indicates that the addition of resin to the board has increased MOE and makes the board more brittle. The MOE value increased when the pressure increased to 8 bar.

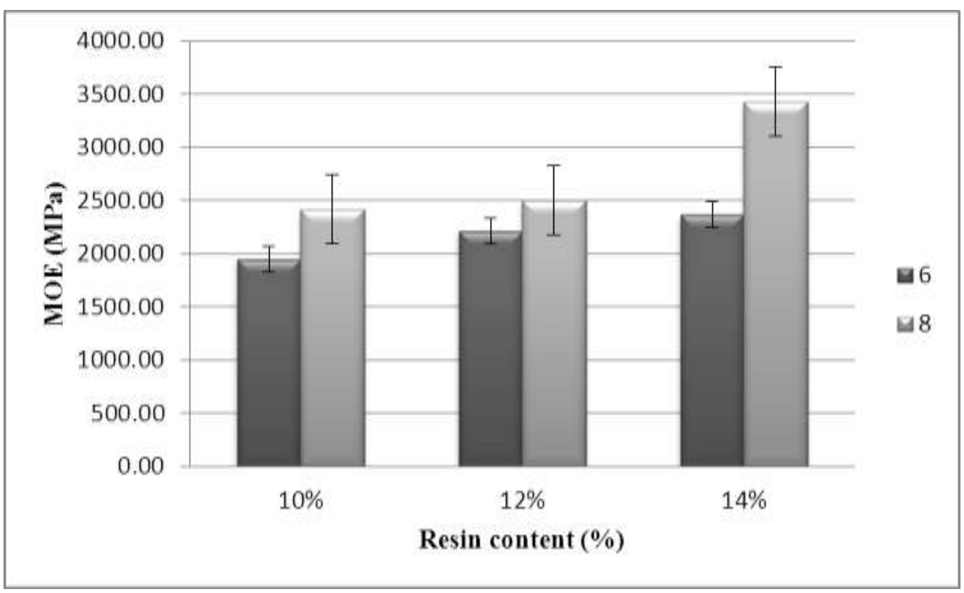

Fig. 2. Modulus of elasticity of samples manufactured with different refining conditions (pressure 6 and 8 bar) and resin contents

The fact that the MOR and MOE values increased with an increase of digestion pressure at 8 bar is probably due to the short fibres, which subsequently make the mat more easily compressed for better compaction. Furthermore, the presences of fine fibre readily allowed gap filling within fibre-to-fibre.

Internal bond tests were performed to determine the interfacial bonding strength between fibres in the boards. The results (Fig. 3) show that the resin content and pressure have significantly affected the mean IB values of the boards. The IB values of the MDF improved when the resin content was increased. MDF with 14% resin content display significantly (< .0001) higher IB values compared to those bonded at resin loadings of 12% and 10%, respectively. The results indicate that a higher amount of resin encourages stronger interfacial bonding between fibres in the boards, thus enhancing the ability of the boards to withstand the pulling force created in the test.

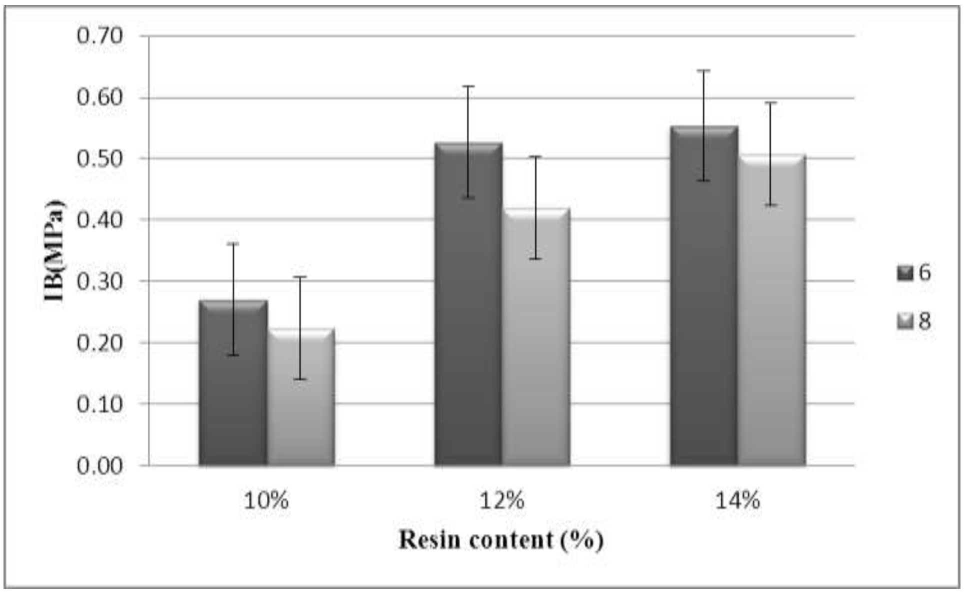

Fig. 3. Internal bonding of samples manufactured with different refining conditions (pressure 6 and 8 bar) and resin contents

Effects of Refining Conditions and Resin Content on the Physical Properties of MDF Samples

Results of the water absorption test are summarized in Fig. 4. The results showed that water absorption decreased with an increase of resin content at the two different pressures. This may be due to the ability of the chemical components in the resin to cross-link with the hydroxyl groups of the kenaf fibres and reduce the hygroscopicity of the boards.

Hygroscopic expansion can be affected by various factors of the resin such as the monomer, the polymerization rates, the cross-linking and pore size of the polymer network, the bond strength, the interaction between polymer and water, the filler, and the resin-filler interface (Saad and Kamal 2012). In addition, high pressurize refining removes hydrophobic components such as extractives and results in better physical properties (Halvarsson *et al.* 2010).

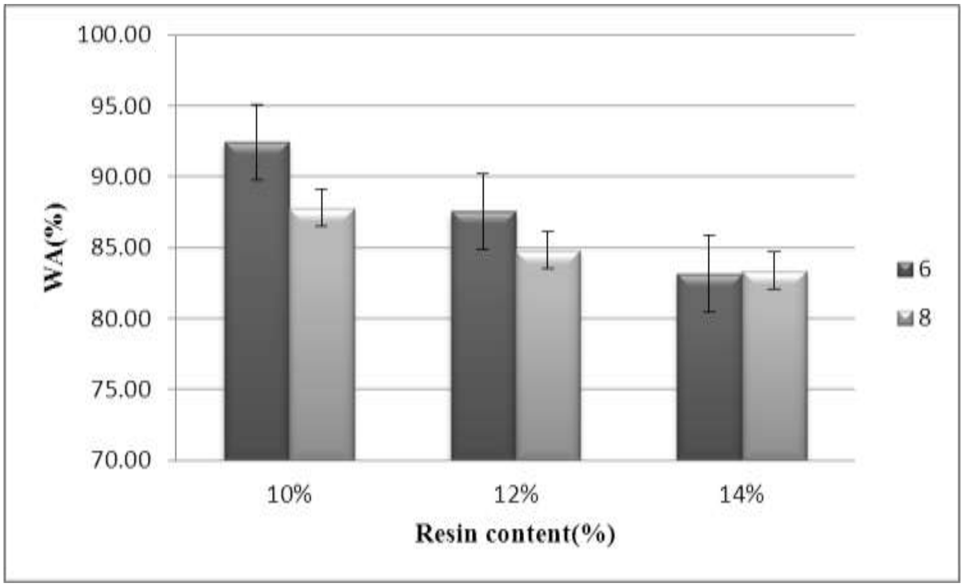

Fig. 4. Water absorption of samples manufactured with different refining conditions (pressure 6 and 8 bar) and resin contents

The results of thickness swelling are displayed in Fig. 4. It is apparent from the results that thickness swelling properties display behavior similar to water absorption. The TS values also decreased when the resin loading increased from 10 to 14%.

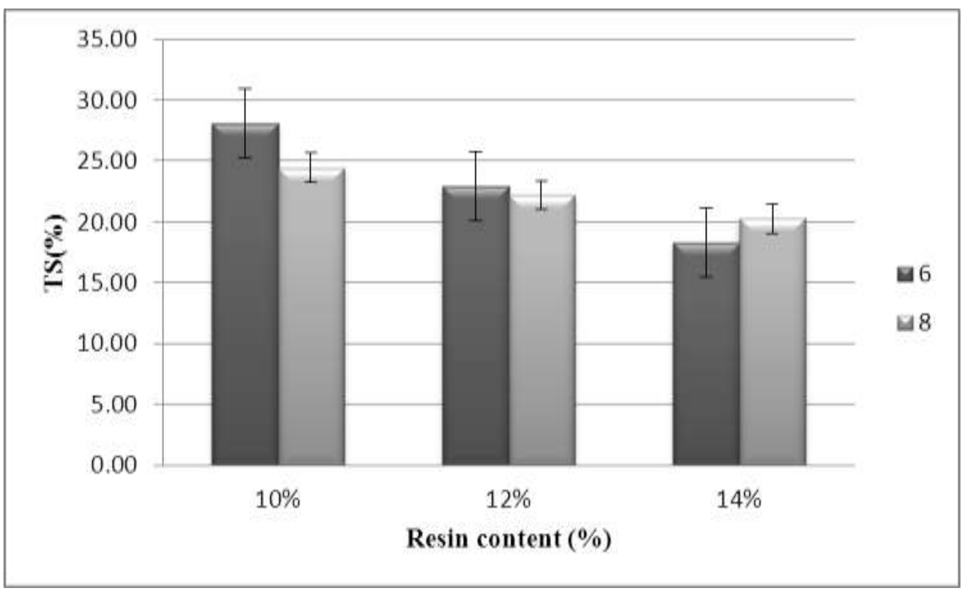

Fig. 5. Thickness swelling of samples manufactured with different refining conditions (pressure 6 and 8 bar) and resin contents

The present results agree with the findings of Labosky *et al.* (1993), who observed that an increase in resin content of the boards from 6 to 12% resulted in a 174% increase in IB strength, a 68% increase in the MOR, and a 40% increase in the MOE, whereas TS and WA properties decreased by 113% and 60%, respectively (Labosky *et al.* 1993). Saad *et al.* (2012) developed low density particleboard using kenaf at three resin levels (8, 10, and 12%) and three different densities (350, 450, and 550 kg/m^3). They found that samples bonded with high resin content resulted in high values of MOR, MOE, IB, and screw withdrawal, but low in WA and TS (Saad and Kamal 2012). Kalaycioglu and Nemli (2006) studied the use of kenaf stalks as raw materials for particleboard manufacturing (Kalaycıoglu and Nemli 2006). They evaluated effects of press temperature, time, pressure, density, and shelling ratio; all parameters were effective on the physical and mechanical properties with the exception pressure. Xu *et al.* (2003) reported that bending strength and IB were improved in binderless particleboards developed from kenaf core using the steam-injection pressing by an increase in steam pressure from 0.6 to 1.0 MPa (Xu *et al.* 2003). Xu *et al.* (2006) found that kenaf core binderless fibreboards manufactured with high digestion pressure (0.8 MPa) and extended heating time during the refining process had high IB strength and low TS, but low bending strength.

CONCLUSIONS

1. Thermo-mechanical refining and resin content had significant effects on the physical and mechanical properties of the medium density fibreboard made from kenaf (*Hibiscus cannabinus* L.) stem.
2. MDF manufactured with a high resin content and under high pressure displayed low WA and TS but high MOR, MOE, and IB.
3. Under high refining pressure (8 bar) and resin content (14%), the MDF had an optimum WA of 83.12%, TS of 20.2%, MOR of 25.3 MPa, MOE of 3450 MPa, and IB of 0.51 MPa.

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