

Mechanical and physical properties of urea-formaldehyde bonded kenaf core particle boards

(Sifat mekanikal dan fizikal papan zarah teras kenaf terikat urea-formaldehid)

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Keywords: *Hibiscus cannabinus*, urea-formaldehyde; UF resin loading

Abstract

Kenaf (*Hibiscus cannabinus*) core particle boards bonded with urea-formaldehyde (UF) resin were produced with three different densities, i.e. 350 kg/m³, 450 kg/m³ and 550 kg/m³. Three UF resin loadings, namely, 8%, 10% and 12% were sprayed on the kenaf core particle boards. The boards produced were evaluated for their mechanical properties comprising of modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB), and physical properties including water absorption (WA) and thickness swelling (TS). It was found that kenaf core particle boards manufactured with 550 kg/m³ density and 12% UF loading had superior properties in terms of MOR, MOE, IB, water absorption and thickness swelling. Statistical analysis indicated that IB, WA and TS were influenced by kenaf core content and resin loading but MOR and MOE were influenced by kenaf core content only.

Introduction

A worldwide shortage of forest resources triggered an increase in awareness among people in the wood-based industry to find alternative supply of resources of raw materials from the forests for production of composites (Sampathrajan et al. 1992). Alternative resources such as the fast-growing species like kenaf (Izran et al. 2010c) and bamboo (Zaidon et al. 2004; Anwar et al. 2005) as well as lesser-known or under-utilised species (Abood 2008) have been discovered to reduce the effect of the shortage. Among the alternative resources, crops like kenaf seems more preferable because of its fibres, especially the outer part which is low cost, low density,

high in toughness, suitable for recycling, had acceptable strength properties and biodegradability (Xue et al. 2007).

In Malaysia, kenaf is still a new crop and great encouragement is given to promote acceptance of the crop. Kenaf is a warm season annual fibre crop closely related to cotton (*Gossypium hirsutum* L., Malvaceae) and okra (*Abelmoschus esculentus* L., Malvaceae) (Charles et al. 2002). This crop possesses the ability to grow fast and has two types of fibres i.e. the bast (outer part) and core (inner part) which can be utilised as components of paper products, building materials, absorbents, textiles and livestock feed (Charles and Bledsoe 2001). Kenaf is able to reach a

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height of 3 to 5 m within 3 to 5 months, depending on the environmental condition of the place it is planted. It can supply between 12 and 25 t/ha of biomass annually when planted under warm and wet conditions (Charles and Bledsoe 2001).

The bast fibre has obtained greater attention than the kenaf core. This is probably due to its mechanical properties which are greater than the core (Xue et al. 2007; Paridah et al. 2009). The kenaf core is light and porous, having a bulk density of 0.10 – 0.20 g/cm³, and can be easily crushed into very light weight particles. The cellulose and lignin contents of the kenaf core are quite similar i.e., between 31 – 33% and 23 – 27% respectively, compared to wood (Charles et al. 2002). However, only the kenaf bast fibres are largely used in the paper industry and utilisation of the kenaf core in the industry is still limited. Many studies revealed that the kenaf core also has potential to be used for the production of insulation composites (Charles and Bledsoe 2001; Sheikkariem 2000), medium-density particle boards (Charles et al. 1998; Grogriou et al. 2000), fire retardant-treated particle boards (Izran et al. 2009a; Izran et al. 2009b; Izran et al. 2009c; Izran et al. 2010b;) and polymer composite (Mohamad Jani 2010). Therefore, a study was conducted to enhance the utilisation of the kenaf core by promoting the material to be used as an input for the production of particle boards. This study was conducted to investigate the influence of resin and kenaf contents on the mechanical and physical properties of low density kenaf core particle board.

Materials and methods

Preparation of kenaf particles

The kenaf particles were prepared from the core of four-month old kenaf stalks, variety V-36, obtained from the kenaf research plot at MARDI Serdang, Selangor, Malaysia. The kenaf core was separated from the bast using the kenaf decorticating machine. During the separation process, the kenaf core was

simultaneously cut into chips of 2 – 3 cm size. The kenaf core chips were then flaked into particles with sizes between 2 and 3 mm using a knife ring flaking machine. The particles were then dried in the oven (unitherm drier) at 70 °C for two days to achieve 5% moisture content (MC).

Urea-formaldehyde (UF) resin addition process

The UF resin at 64% solid content, obtained from Dynea (M) Sdn. Bhd, Senawang, Negeri Sembilan, Malaysia, was used for bonding the kenaf particles. The particles were mixed with 8%, 10% and 12% UF resins separately using a blender. Each of the resin loading was based on the oven dry weight of the kenaf core particles. The resins and the particles were mixed in the blender for 5 min to ensure that the particles were evenly mixed with the resins.

Particle board making

After the mixing process, the kenaf mixture was removed from the blender and scattered in a square-shaped former with dimensions of 340 mm x 340 mm, which was first placed on a caul plate covered with a teflon fibre sheet. The kenaf mixture was then pre-pressed in the cold press machine (Model FRIM Cold Press) at a pressure of 35 kg/cm² and subsequently pressed in the hot press machine (Model Taihei) to 12 mm thickness at 170 °C for 6 min. The particle boards were then exposed to ambient condition to cool them down and to encourage curing of the resin. Boards at densities of 350 kg/m³, 450 kg/m³ and 550 kg/m³ were produced, with 6 samples prepared for each density for the testing purposes.

Testing procedures

All particle board samples were kept in an air-conditioned room at 20 ± 2 °C and 65 ± 5% relative humidity until a constant mass was obtained prior to the testing. A constant mass was obtained when the results of two successive weighing operations, carried out

at an interval of 24 h, do not differ by more than 0.1% of the mass of each particle board (Anon. 1993a). The conditioning process was employed to ensure that the resin in the particle board had cured uniformly. The boards were then cut into sizes of 290 mm length × 50 mm width for MOR and MOE tests (Anon. 1993a), 50 mm length × 50 mm width for internal bond (Anon 1993b), water absorption and thickness swelling tests. The water absorption (WA) and thickness swelling (TS) were calculated after immersing the samples in water at 20 °C for 24 h (Anon. 1993c).

Experimental design and statistical analysis

A completely randomised design (CRD) in factorial arrangements was used for the experiments. All the data were analysed using Statistical Analysis Software (SAS 9.1) to study the effect of kenaf content and UF resin loading on mechanical and physical properties of the boards. Any interaction between board density and UF resin was also studied. The differences among means were analysed according to Duncan Multiple Range Test (DMRT) at $p < 0.05$ level.

Results and discussion

Mechanical properties

Table 1 shows the modulus of rupture (MOR) results of kenaf particle boards fabricated using UF resins at different resin loadings. It was observed that the mean MOR values increased significantly with the increase of resin loading from 8 to 10%. However, there was no significant difference of MOR when UF loading rose from 10 to 12%. These results showed that the presence of resin has significant positive effect on bending strength especially at UF loading of 8 to 10%. An increase of board density also increased the MOR values, most of them were significantly different from board density of 350 kg/m³ to 450 kg/m³ and 550 kg/m³. The highest mean MOR values were recorded from samples with a density of 550 kg/m³ which was 16.77 MPa. Density

of a board is influenced by the amount of particles used to fabricate the board (James et al. 1999). The higher the density, the larger the amount of particles used. Larger amount of particles were expected to reduce voids between particles in the particle boards and enhance the resistance to rupture.

Since the MOR indicates the ability of a specimen to withstand a transverse (bending) force perpendicular to its longitudinal axis (Jacobs and Kliduff 1994), MOR results of the boards at higher density and resin contents were able to withstand such force. The wood particles influenced the board strength performances which clearly contributed to the MOR where a greater knead content produced a greater MOR value as shown in *Table 1*.

The modulus of elasticity (MOE) is the slope of the tangent line at the stress point of proportional limit (Anon 1993a). MOE is related to the stiffness of a board, and the higher the MOE, the higher the stiffness. It can be seen that the value of MOE increased significantly with the increase in board density (*Table 1*). The results were in agreement with previous studies by James et al. (1999). The density of the board was also found to play a role in increasing the stiffness, particularly for boards with a density of 550 kg/m³ compared to those of 450 kg/m³ and 350 kg/m³ densities. The inherent stiffness of the particles was expected to influence the overall stiffness of the boards positively. The mean MOE values of the board density at 550 kg/m³ was the highest (*Table 1*). Increasing the UF loading levels from 8 – 12% on the board was not significantly affecting the MOE.

Internal bond (IB) test was conducted to determine the interfacial bonding strength between fibres in the boards (Anon 1993b). The results in *Table 1* shows that the resins had significantly affected the mean IB values of the boards. The values were better when the loading of the resins was increased from 8 to 12% especially at 550 kg/m³ board density. The results indicated that a higher amount of resin encouraged stronger

Table 1. Effect of board density and resin level on mechanical properties of kenaf core particle board

Source of variation	MOR (MPa)	MOE (MPa)	IB (MPa)
Density (D)	**	**	**
350 kg/m ³	4.91c	645.39c	0.36c
450 kg/m ³	10.30b	1436.12b	0.56b
550 kg/m ³	16.77a	2025.11a	0.67a
Resin (R)	**	ns	**
8%	9.55b	1302.71a	0.46c
10%	11.09a	1407.28a	0.50b
12%	11.34a	1396.65a	0.63a
D × R	ns	ns	**
CV	10.72	13.21	11.88
Mean	10.66	1368.87	0.53

Means with the same letter within the same column are not significantly different at 5% level of significance. MOR = modulus of rupture, MOE = modulus of elasticity and IB = internal bond

interfacial bonding between fibres in the boards, thus prolonging the ability for the boards to withstand the pulling force created through the test. *Table 1* demonstrated that boards manufactured at 550 kg/m³ density was significantly higher in internal bond (IB) strength compared to those at 450 kg/m³ and 350 kg/m³ board densities. The lower mean IB values found at the lower board density (350 kg/m³) were expected due to the existence of more voids in the boards compared to boards at higher densities. The voids caused inefficiency of the inter-fibre bonding (Ashori and Nourbakhsh 2008).

The interaction among board densities and resin levels did not show significant differences in performance of MOR and MOE. The mean values of MOR and MOE obtained were 10.66 MPa and 1368.87 MPa respectively. Meanwhile, very significant interactions between board densities and resin levels were found for IB as shown in *Table 1* and the reasons have already been discussed. The combinations of these two parameters produced a mean IB value of 0.53 MPa.

Table 2. Effect of board density and resin level on physical properties of kenaf core particle board

Source of variation	WA (%)	TS (%)
Density (D)	**	**
350 kg/m ³	189.45a	25.10a
450 kg/m ³	142.61b	25.28a
550 kg/m ³	111.32c	20.88b
Resin (R)	**	**
8%	156.76a	25.85a
10%	146.39b	24.93a
12%	140.23c	20.49b
D × R	*	**
CV	5.87	9.38
Mean	147.79	23.75

Means with the same letter within the same column are not significantly different at 5% level of significance. TS = thickness swelling, WA = water absorption

Physical properties

The results of the physical tests including the water absorption and thickness swelling tests are summarised in *Table 2*. There was a very significant decrease in the water absorption (WA) with the increase of UF resin content from 8 – 12%. The decrease in water absorption corresponding to influence

of UF intake may be due to the chemical components in the resin that is capable of cross-linking with the hydroxyl groups of the kenaf fibres, hence reducing the hygroscopicity of the boards. Hygroscopic expansion can be affected by various factors of the resin such as the monomer, polymerisation rates, cross-linking and pore size of the polymer network, bond strength, interaction between polymer and water, filler and resin-filler interface (Yong et al. 2011). The 12% resin loading of UF board gave the lowest water absorption values. The water absorption was also found to decrease very significantly as the kenaf particle loading increased from board density of 350 kg/m³ to 550 kg/m³. This phenomenon may be explained by the theory of void over volume of board. Greater existence of void mostly found in low density particle board may provide spaces which encourage water absorption (Loh et al. 2010). In low density board, the highly porous structure of the board allows water to penetrate into the board and increase water uptake resulting in high water absorption, which at the same time, causes the board to swell and subsequently increase the thickness swelling (TS). In high density boards, the higher compaction ratio implies that more compressive deformation has been imparted onto the particles during hot pressing and the particles were under greater compressive set (Wong et al. 1999). This situation reduces the formation of voids and reduces water absorption.

Results of thickness swelling are displayed in *Table 2*. The thickness swelling was measured by calculating the difference between the thicknesses of the sample before and after soaking in water for 24 hours. It was found that the responses in thickness swelling are almost similar to those of water absorption since thickness swelling is related to water absorption. Thickness swelling values of UF bonded boards dropped significantly as UF resin loading rose from 8 – 12%. Board density seemed to influence the thickness swelling

of kenaf particle board. The result indicated that thickness swelling values decrease significantly with increase in board densities.

The results in *Table 2* indicated that water absorption (WA) and thickness swelling (TS) properties were significantly affected by the board density and resin loading. The overall mean of TS and WA were 23.75% and 147.79% respectively. The higher board content was able to reduce water absorption into the board, thus reducing the TS and WA percentages which might be due to less void area in the board. Meanwhile the UF resins at higher levels absorbed less water after the kenaf particle has been bonded and thus improved the TS and WA properties.

Conclusion

The content of kenaf core and UF resin loading influenced the mechanical and physical properties of the kenaf core particle boards. The particle boards manufactured with a density of 550 kg/m³ and 12% UF loading was superior in MOR, MOE, IB, water absorption (WA) and thickness swelling (TS) properties. Statistical analysis showed that IB, WA and TS were influenced by kenaf core content and resin loading while MOR and MOE were influenced by the kenaf core content only.

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Abstrak

Papan zarah teras kenaf (*Hibiscus cannabinus*) terikat dengan resin urea-formaldehid (UF) telah dihasilkan dengan tiga jenis ketumpatan iaitu 350 kg/m³, 450 kg/m³ dan 550 kg/m³. Tiga muatan resin UF, 8%, 10% dan 12%, telah disemur ke atas papan zarah teras kenaf. Papan zarah yang dihasilkan telah dinilai sifat mekanikalnya termasuk modulus kepecahan (MOR), modulus keanjalan (MOE) dan ikatan dalaman (IB). Manakala sifat fizikal yang dinilai termasuk keserapan air (WA) dan pengampulan ketebalan (TS). Keputusan menunjukkan papan zarah teras kenaf pada ketumpatan 550 kg/m³ dan muatan resin UF pada 12% didapati mempunyai sifat yang lebih baik dari segi MOR, MOE, IB dan sifat fizikal seperti keserapan air dan pengampulan ketebalan. Analisis statistik menunjukkan IB, WA dan TS dipengaruhi oleh kandungan teras kenaf dan muatan resin tetapi bagi MOR dan MOE hanya dipengaruhi oleh kandungan teras kenaf sahaja.