BONDING PROPERTIES AND PERFORMANCE OF MULTI-LAYERED KENAF BOARD

MT Paridah[1,*], AW Nor Hafizah[1], A Zaidon[1], I Azmi[2], MY Mohd Nor[3] & MY Nor Yuziah[4]

[1]*Institute of Tropical Forestry and Forest Product, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia*
[2]*Faculty of Civil Engineering, MARA University of Technology, 40000 Shah Alam, Selangor Darul Ehsan, Malaysia*
[3]*Forest Research Institute Malaysia, 52109 Kepong, Selangor Darul Ehsan, Malaysia*
[4]*Malayan Adhesive and Chemical (MAC), 9 Jln Utas 15/7 Seksyen 15, 40200 Shah Alam, Selangor Darul Ehsan, Malaysia*

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PARIDAH MT, NOR HAFIZAH AW, ZAIDON A, AZMI I, MOHD NOR MY & NOR YUZIAH MY. 2009. Bonding properties and performance of multi-layered kenaf board. Kenaf (*Hibiscus cannabinus*) has recently been introduced to the Malaysian bio-composite industry. Based on their basic properties, both the bast fibres and core material of kenaf are distinctly different. While bast fibres are stiffer and low in wettability, the core material of kenaf is weaker and has excellent absorbing properties. This study evaluated the properties of kenaf board made from a combination of bast fibres and core material. The bast fibres were separated first from the core, followed by pre-treatment with NaOH, then combing until the fibres became loose. The properties of kenaf board were tested using MS standards 1787: 2005. An analysis of variance was carried out to study the effects of resin types and bast to core proportion on the boards. The buffering capacity study revealed that kenaf bast, kenaf core and rubberwood behaved similarly in alkali but differently in an acidic condition. Both the kenaf bast and core were relatively less stable in acid compared with rubberwood. Due to its morphological characteristics, the kenaf core inner surface exhibited higher wettability than the outer surface. There was significant interaction between resin type and the proportion of bast:core at $p < 0.01$. Generally, boards made from 100% kenaf core and bonded with urea formaldehyde (UF) resin had superior performance. The mechanical properties [modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB)] of the boards were significantly influenced by the amount of bast fibre in the board—the higher the amount, the poorer the strengths. This effect, however, was reversed for thickness swelling (TS). Only UF-bonded kenaf-based boards had comparable water absorption (WA) property to that of the control (100% rubberwood). The incorporation of low molecular weight phenol formaldehyde (LPF) resin in the fibres had mixed effects on board properties. The effects varied based on the resin used; it improved the MOE and MOR of the board but not the IB, TS and WA when used with UF resin. It improved the IB only when used with melamine urea formaldehyde (MUF) resin. The best performance was given by boards made from 100% kenaf core irrespective of the type of resin used. All kenaf boards in this study had higher MOR than that of 100% rubberwood. Insufficient curing of LPF resin was identified as the main factor for the poor performance of LPF-bonded boards.

Keywords: Wettability, buffering capacity, bast fibre, core material

PARIDAH MT, NOR HAFIZAH AW, ZAIDON A, AZMI I, MOHD NOR MY & NOR YUZIAH MY. 2009. Ciri-ciri rekatan dan prestasi papan kenaf pelbagai lapisan. Kenaf (*Hibiscus cannabinus*) kini diperkenalkan dalam industri bio-komposit di Malaysia. Berdasarkan ciri asasnya, kedua-dua ciri gentian kulit dan bahan teras kenaf nyata berbeza. Gentian kulit lebih keras dan mempunyai nilai pembasahan yang lebih rendah berbanding dengan bahan teras kenaf yang sangat lemah dan mempunyai ciri penyerapan yang baik. Kajian ini menilai ciri papan kenaf yang diperbuat daripada kombinasi gentian kulit dan bahan teras kenaf. Mula-mula gentian kulit dipisahkan daripada teras, diikuti oleh pra-rawatan dengan NaOH dan disikat sehingga gentian menjadi longgar. Ciri papan kenaf diuji menggunakan Piawaian Malaysia MS 1787: 2005. Analisis varians dijalankan untuk menyelidiki kesan jenis perekat dan nisbah kulit:teras terhadap papan. Kulit kenaf, teras kenaf dan kayu getah mempunyai ciri keupayaan menampan yang sama iaitu sensitif dalam keadaan alkali. Dalam keadaan asid, kulit kenaf dan teras kenaf agak kurang stabil berbanding dengan kayu getah. Disebabkan ciri morfologinya, permukaan dalam teras kenaf mempamerkan nilai pembasahan yang lebih tinggi daripada permukaan luar. Jenis perekat dan nisbah kulit:teras memberi kesan signifikan kepada prestasi papan pada $p < 0.01$. Secara amnya, papan yang diperbuat daripada 100% bahan teras kenaf dan dilekat dengan perekat urea formaldehid (UF) memberikan prestasi terbaik. Ciri-ciri mekanik [modulus kekenyalan (MOE), modulus kepecahan (MOR), ikatan dalaman (IB)] papan sangat dipengaruhi oleh jumlah gentian kulit yang digunakan—lebih banyak gentian kulit, lebih lemah papan. Bagaimanapun, perkara yang sebaliknya berlaku bagi pembengkakan ketebalan (TS). Hanya papan kenaf yang menggunakan perekat UF mempunyai serapan air (WA) yang setanding dengan nilai yang dicapai oleh papan serpai kawalan (100% kayu getah). Penggabungan perekat fenol formaldehid berjisim molekul rendah (LPF) dalam gentian menghasilkan pelbagai kesan terhadap ciri papan. Jika digunakan dengan perekat UF, MOR dan MOE dipertingkatkan tetapi tidak untuk IB, TS dan WA. IB dipertingkatkan sekiranya digunakan dengan melanin urea formaldehid (MUF). Papan yang diperbuat daripada 100% teras kenaf menunjukkan prestasi terbaik tanpa dipengaruhi oleh jenis perekat. Kesemua papan kenaf mempunyai MOR yang lebih tinggi daripada papan daripada 100% kayu getah. Pengesetan yang tidak cukup dikenal pasti sebagai faktor utama papan berperekat LPF menunjukkan prestasi yang lemah.

* E-mail: parida_introb@yahoo.com

INTRODUCTION

Rubberwood is almost exclusively used as raw material for the production of both particleboard and medium density fibreboard (MDF) in Malaysia. It is also responsible for the establishment and growth of the Malaysian wood-based industries in particular MDF, particleboard, wood lamination and furniture. Due to the wide range of applications, the price of rubberwood has become very competitive and relatively higher in the last decade.

As more rubber plantations are being converted into oil palm plantations or into housing areas, a shortage of rubberwood supply is inevitable. To meet the demand for rubberwood, kenaf has been identified as one of the potential raw materials since it is fast growing and could be harvested in just four or five months. Kenaf has great potential in industries that consume high volumes of wood/fibre material such as those of pulp and paper, MDF and particleboard.

Kenaf stalk, which comprises a woody inner core and fibrous outer bast, is a rich source of fibre. The core of kenaf is light and porous, having a bulk density of 0.10–0.20 g cm^{-3}. It can easily be crushed into very light-weight particles. Compared with wood, the cellulose and lignin contents of kenaf core are quite similar (between 31–33% and 23–27% respectively) but the hemicellulose content is much higher (Alireza *et al.* 2003). The fibres of kenaf bast, on the other hand, is longer than those of softwood, i.e. 10 mm in the former (Kawai 1999) and 5 mm in the latter (Rymsza 1999). The diameter of its fibre is smaller than that of softwood, but its tensile strength is much greater (Kawai 1999). Kenaf plant produces 3–6 tonnes of dry fibre per hectare, which is three to five times more biomass compared with most forest species. Based on this amount, and the possibility of planting twice a year, kenaf could be a viable alternative source material for the manufacture of MDF, particleboard, and pulp and paper. Kenaf can either be used in the form of bast—whole stalk or core (Webber *et al.* 1999). Since the ratio of bast to core is low (40:60), it is more economical to use both the bast fibres and the core material for the production of kenaf board. Kenaf fibres possess great strength to weight ratios and these make them more appealing for composite experimentation.

Since bast fibres are long and straight, it provides better strength in the final product if they are arranged parallel to each other. If both bast fibre and the light weight core material can be combined in making kenaf board, we may be able to optimize both features, i.e. strong and light weight. By placing the fine particles on the surfaces, the final board would have a more homogeneous surface layer which is crucial for subsequent lamination process. Loh *et al.* (2007) showed that boards made from 100% bast fibres had poor performance due to inferior bond strength which was caused by the lack of fibre wetting. By laying the different raw materials (bast and core) in different layers and treating the bast fibres with additional resin adhesive, i.e. low molecular weight phenolic resin (LPF), the performance of the layered board may be improved. The effectiveness of using LPF to improve the properties of particleboard has been reported by several authors (Haygreen & Gertjejansen 1971, Kajita & Imamura 1991, Imamura *et al.* 1998, Paridah *et al.* 2006).

Surface wettability and buffering capacity are two important characteristics of wood/fibre material that not only influence the rate of adhesive penetration and curing but also the extent of adhesion between the wood and the adhesive. Wetting can be quantified by determining the equilibrium contact angle formed by the intersection of the solid, liquid and gas phases (Freeman & Wangaard 1960). When good wetting occurs, the contact angle becomes very small and the liquid spreads or flows spontaneously across the surface. Buffering capacity measures the resistance of wood/fibre to change in acidity or in alkalinity. Both the pH and buffering capacity of the wood/fibre at the glueline affect the cure of the resin. Knowing the buffering capacity of a fibre helps determine the amount of buffering agent required in an adhesive to prevent changes in pH at the glueline. These changes, if not prevented, will influence the rate of curing of the resin, and subsequently the working parameters, i.e. assembly time and press time, and press temperature will have to be adjusted.

This paper evaluates the potential of kenaf as raw material for the production of multi-layered kenaf board. The work comprised two main aspects—(1) evaluation of surface wettability and buffering capacity of kenaf, and (2) evaluation of strength and dimensional stability of multi-layered kenaf board bonded with various types of commercially available synthetic resins. A low molecular weight phenol formaldehyde (LPF) resin was also used in this study to pre-treat kenaf particles prior to normal blending to improve the dimensional stability of the resulting kenaf board.

MATERIALS AND METHODS

Source of kenaf

Kenaf (*Hibiscus cannabinus*), variety Tainong-2, was used in this study. It was supplied by a kenaf plantation in Sintok, Kedah.

Bonding properties of kenaf

Kenaf and rubberwood (as control) were ground to pass through a sieve with 53 µ mesh. The aqueous wood extract was prepared by refluxing 100 g of the finely ground wood in 1000 ml distilled water for about 1 hour. After refluxing, the mixtures were filtered using a filtering glass crucible #1 with an aspirator vacuum. The distillate was diluted to 250 ml and cooled to room temperature before titration. The solution was then titrated using a Labx Titration analysis software system with 0.01 N hydrochloric acid (HCI) until it reached pH 3.0. The procedure was repeated using another sample with 0.01 N sodium hydroxide (NaOH) until it reached pH 11. The pH values were recorded after every 5 ml of titration. A graph, pH versus volume (ml), was plotted to observe the changes in pH. The experiment was carried out in three replicates and the values were maintained within 5% deviation.

Determination of contact angle of kenaf

Kenaf core, kenaf bast and rubberwood samples 20 × 20 × 10 mm were used for the wettability study. The samples were taken from both the outer and inner parts of kenaf stalk. A microscope with an attached camera was used to observe the contact angle. A liquid droplet, either from water, 0.1N HCl or 0.1N NaOH was then photographed after 0, 60, 120 s, 5 min and every 5 min interval until 20 min lapse time, or until the droplet was completely spread onto the wood surface. Since the value of contact angle is time dependent, a time frame of between 10 s and 20 min was set for this study. If the contact angle is 0° in less than 10 s after the droplet was made on the surface, the surface was regarded as spontaneous wetting, but if the angle remained > 0° after 20 min, the surface was considered as non-wetting.

Preparation of kenaf bast fibre and core particles

Retting of kenaf bast and production of bast fibres

Bast of kenaf was stripped from the stalk manually and air dried to about 18–20% moisture content (MC). Approximately 18 kg of dried kenaf bast was submerged in NaOH solution (2.5% concentration) for 24 hours. Then the alkali solution was drained and the bast was washed with tap water. Following this, the container was filled with water and the mixture was heated to 70 °C for six hours. The step was repeated everyday for three days with a total of 18 hours heating time. The retted bast was then rinsed, washed, combed and hung at ambient condition to produce long and clean bast fibres. The air-dried bast fibres were cut into 300 mm long fibres and further dried in an oven to about 5% MC. The yields of kenaf bast were calculated as:

$$\text{Yield (\%)}_{\text{after retting}} = \frac{\text{Weight}_{\text{initial}} - \text{Weight}_{\text{final}} \times 100\%}{\text{Weight}_{\text{initial}}}$$

$$\text{Yield (\%)}_{\text{after combing and cleaning}} = \frac{\text{Weight}_{\text{initial}} - \text{Weight}_{\text{final}} \times 100\%}{\text{Weight}_{\text{initial}}}$$

Preparation of core particles

The core material was chipped using a Pallman chipper and reduced to smaller particles on a Pallman knife ring flaker. The core particles were then screened and only those of sizes 1–2 mm were used for making the kenaf board. The average final moisture content of the particles was 5%.

Manufacture of kenaf board

Two types of binder (10%, w/w) were used in this study: urea formaldehyde (UF) and melamine urea formaldehyde (MUF). To improve the dimensional stability of the boards, 2% w/w of low molecular weight phenol formaldehyde (LPF) resins were sprayed onto the bast fibres/ core particles prior to normal blending.

The experiment involved five types of kenaf board of different structures (Figure 1). The target density of all types of board was 0.50 g cm^{-3}. The size of board was 340 × 340 × 10 mm. Four types of resin combinations were used: (1) UF only, (2) MUF only, (3) LPF + UF and (4) LPF + MUF. A total of 40 boards were made (5 types of board with 4 resin combinations and 2 replicates each).

Both the core and bast fibres were processed separately. The core particles were placed in a blender which was then rotated prior to spraying the particles with resin binder. The blending took 5 min. The long bast fibres were first divided into three parts. Each part constituted fibres that were arranged in parallel to make three fibre-oriented mats. Each mat was then sprayed with LPF (2% w/w) resin and partially dried in front of a fan. The LPF resin uptake was recorded. The partially dried mat was then sprayed with either UF or MUF resin at 10% w/w resin content. Hence for LPF boards, the total resin content was 12% and for UF and MUF boards the resin content was 10%. The final boards were conditioned at 25 °C and 65% relative humidity for a week. The boards were cut to testing specimens (Table 1) and tested for static bending, internal bond (IB), thickness swelling (TS) and water absorption (WA) according to MS 1787: 2005 (Anonymous 2005).

Statistical analysis

An analysis of variance (ANOVA) and mean separation using least significant difference (LSD) method were carried out to evaluate the effects of fibre sources on the buffering capacity and surface wettability of the fibres and to compare the performance of the various boards. 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 letters (a, b, etc.) implying they are significantly different from each other at $p \leq 0.05$. The effects of resin type and the proportion of kenaf bast:core on modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB), thickness swelling (TS) and water absorption (WA) were analysed.

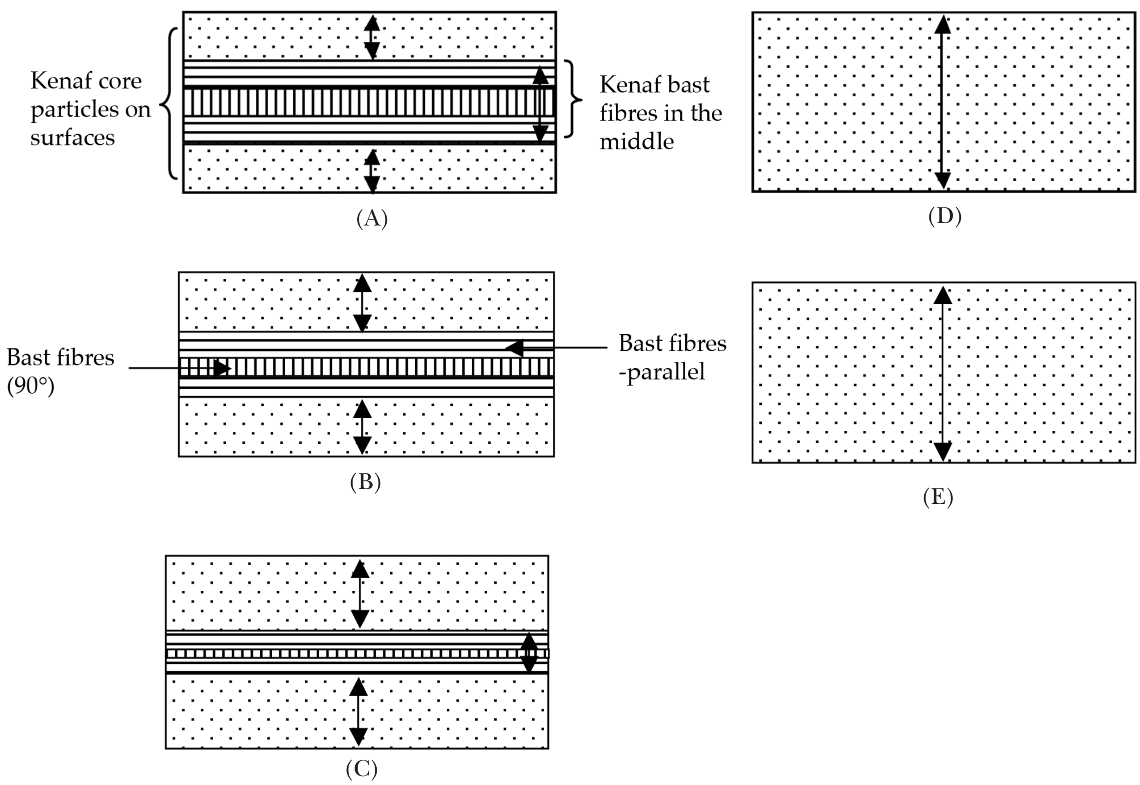

Figure 1 Structure of kenaf board manufactured in the study: (A) 30% core:40% bast:30% core, (B) 35% core:30% bast:35% core, (C) 40% core: 20% bast:40% core, (D) 100% kenaf core and (E) 100% rubberwood (control)

RESULTS AND DISCUSSION

Buffering capacity

The determination of buffering capacity of wood/fibre material prior to any gluing studies is important to ensure effective gluing processes particularly if the adhesive used is pH sensitive such as UF and MUF resins. Extreme values of wood pH had been reported to be troublesome for achieving good adhesive bonds (Paridah *et al.* 2001). As shown in Figures 2a and 2b, kenaf bast, kenaf core and rubberwood behaved differently towards alkali and acid. All the three materials behaved quite similarly when exposed to alkali condition. The rate of change in pH, however, was greater in kenaf core (as shown by a steeper slope) compared with rubberwood and kenaf bast.

Under acidic condition, these materials behaved differently. Apparently, there was greater sensitivity towards acid in both the kenaf bast and core material as compared with rubberwood. As illustrated in Figure 2b, the two lines representing the kenaf materials were steeper and were distinctly apart from that of rubberwood suggesting that they are relatively more sensitive towards acid. Rubberwood is more resistant to acid, thus, has greater buffering capacity. In another study, Paridah *et al.* (2001) also found that rubberwood had greater buffering capacity towards acid compared with sentang (*Azadirachta excelsa*) which explains why rubberwood produces excellent gluebond strength when bonded with acid-curing resins such as UF and MUF. The results imply that the adhesive resins normally used for rubberwood would behave differently in terms of curing rate when used for both the kenaf bast and core, hence the acid catalyst level may need to be adjusted. For an alkali-curing resin such as phenol formaldehyde, minimal adjustment is needed.

Surface wettability

Wetting of the surface by an adhesive is a necessary prerequisite to bond formation. In wettability study, the contact angle formed between a surface and a liquid provides useful information on how well the adhesive wets, spreads and penetrates the wood. Thus, within a certain period of time, a contact angle of > 90° indicates a lack of wetting while a zero contact angle means the liquid/adhesive has completely penetrated the wood surface.

In this study, all the contact angles reached 0° after 20 min with the core inner layer being the fastest (after 90 s) and the bast outer layers the slowest (after 15 min). The contact angle of rubberwood, a control material used in this study, reached 0° only after 3 min. The average contact angles of different sections of kenaf stem after 60 s using different types of liquid are shown in Table 1. Among the three types of liquids, water took relatively longer time to penetrate into the surface of kenaf bast inner surface.

Both the outer and inner layers of kenaf bast were the most difficult to be wet irrespective of the type of liquid used. This behaviour can be attributed to the waxy-like surface observed in the bast which hinders penetration of liquid. Between these two layers, the outer layer exhibited lower contact angle, probably influenced by the presence of residual pectic. The wettability of both the kenaf core inner layer and rubberwood

Table 1 Contact angle of kenaf stem and rubberwood after 60 s determined by liquid droplet spreading method

Sample	Contact angle (°)		
	Distilled water	HCl (0.1 N)	NaOH (0.1 N)
Kenaf bast outer layer	20.77 b	20.17 a	20.08 a
Kenaf bast inner layer	27.25 a	21.25 a	21.42 a
Kenaf core outer layer	20.12 b	18.58 a	19.60 a
Kenaf core inner layer	8.63 c	9.49 b	9.98 b
Rubberwood	10.37 c	11.31 b	12.79 b

Values are the average of three samples and each sample consists of 10 measurements.
Means followed by the same letters in the same column are not significantly different at $p \leq 0.05$.

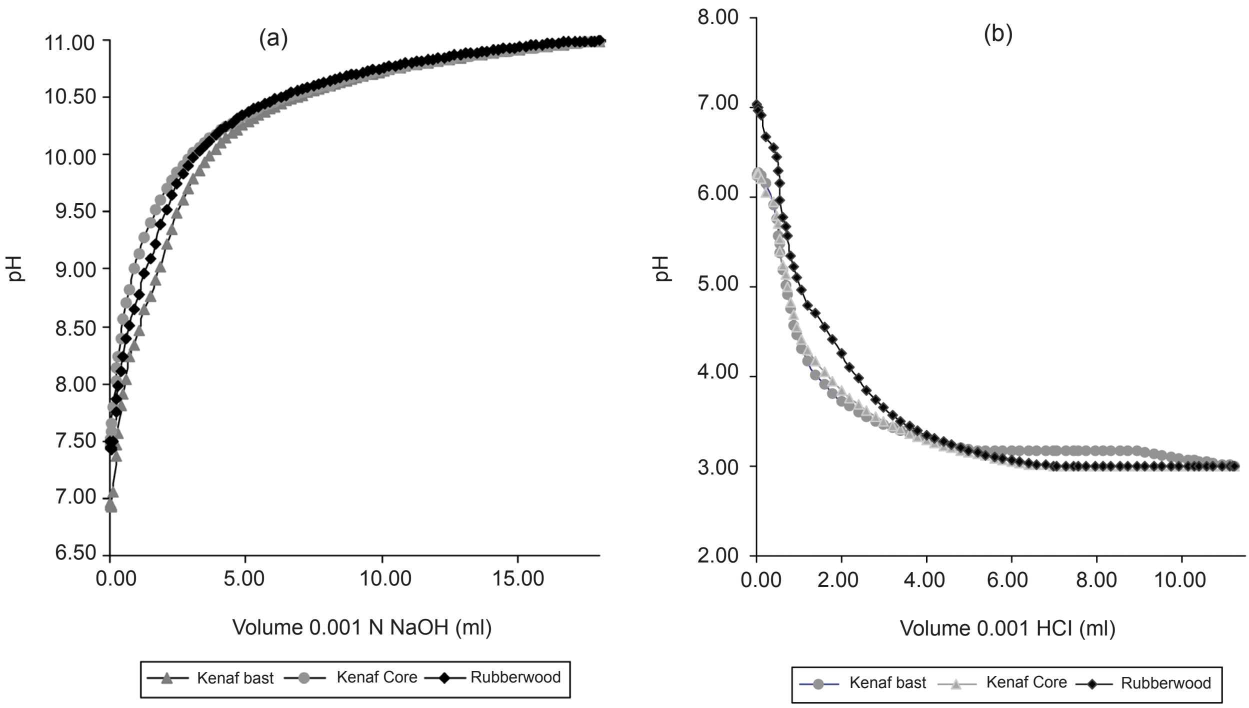

Figure 2 Buffering capacity of kenaf core, bast and rubberwood to (a) alkali and (b) acid

was much better than the others, as indicated by the lower contact angle obtained in as early as 60 s. Between these two, kenaf core inner surface was greater since it had higher intrinsic porosity and thus was more absorbent.

The higher wettability seen in both inner core layer and rubberwood suggests that both materials require shorter time during the blending stage since the adhesive can easily spread and penetrate into the wood/fibre surface. A prolonged blending would result in over penetration, leaving a starved joint, thus, lowering the bond quality.

Performance of kenaf board

The yield of crude bast fibre after water retting was 86.2%. Nevertheless, after further processing (combing and washing) the yield of clean long bast fibre was only 35.3%. The particle recovery analysis of kenaf core material after chipping, flaking and screening processes yielded 92.4% for size > 2 mm, 37.2% for 1–2 mm, 16.2% for 0.5–1.0 mm and 7.2% for < 0.5 mm.

One of the advantages of using kenaf in particleboard manufacture is the possibility of producing low density particleboard due to the lower kenaf density. Compared with rubberwood and kenaf bast, kenaf core is a much lighter material (fibre density 0.19 g cm^{-3}) hence more particles are needed per volume. In addition, the light-weight kenaf core can be compacted much easily without experiencing 'blow' (delamination inside a board due to either moisture or pressure variations) as what may happen if higher density wood such as rubberwood (density ~ 0.58 g cm^{-3}) is used.

The average density of the kenaf board produced in this study was 0.52 g cm^{-3}, 4% higher than the targeted density. As expected, both homogeneous boards (comprising 100% kenaf core and 100% rubberwood particles) had more uniform board density (standard deviation 0.2 g cm^{-3}) compared with that of multilayered (standard deviation 0.6 g cm^{-3}) board. The average moisture content of the conditioned panels was 9.1%.

Figures 3 and 4 give the values of modulus of elasticity (MOE) and modulus of rupture (MOR) respectively for the different types of kenaf boards. Among the five types of boards, those made from 100% kenaf core (board D) were consistently superior in both stiffness (MOE) and strength (MOR) irrespective of the type of adhesive used. Boards bonded with LPF–MUF resin had the highest MOE and MOR:

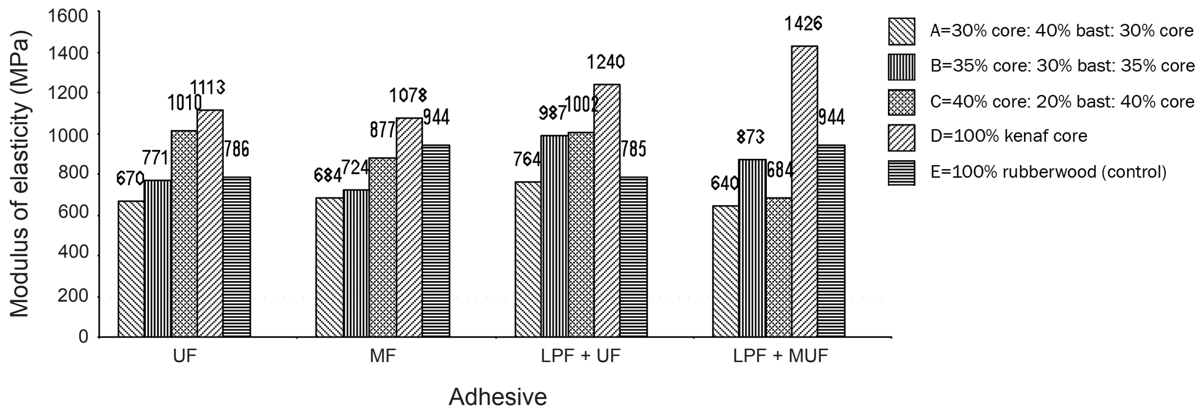

Figure 3 Modulus of elasticity (MOE) of kenaf boards bonded with different types of resins

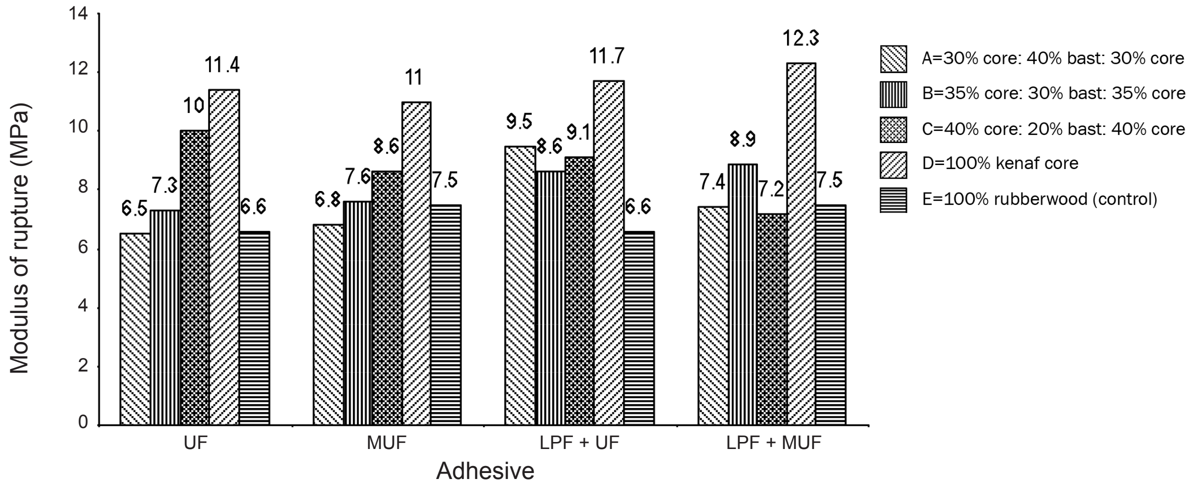

Figure 4 Modulus of rupture (MOR) of kenaf boards bonded with different types of resins

1426 and 12.3 MPa respectively. These values were significantly higher than those obtained for the control board (board E) bonded with the same resin (944 MPa for MOE and 7.5 MPa for MOR). Pretreating the materials with LPF resin prior to board forming had some mixed effects on both the strength and stiffness of the boards, particularly boards A, D and E (Table 2). For instance, board B (35% core:30% bast: 35% core) improved its stiffness between 20 and 28%, and strength by 17% when LPF was used. This method was more effective when UF resin was used as a binder. On the contrary, board C (40% core:20% bast:40% core) experienced a negative effect upon treatment with LPF resin as shown by negative improvements in both stiffness and strength properties (Table 2) except for internal bonding. These effects, however, were less apparent in boards A, D and E. Generally, board D (Figure 4) was superior to the other boards, with MOR of 12.3 MPa, higher than the control board (7.5 MPa). A similar study by Grigoriou *et al.* (2000) using industrial wood chip, kenaf core and kenaf bast showed that 50% of bast in the middle increased the bending strength to 18.2 MPa compared with a mere 17.1 MPa when 25% bast was used.

The use of LPF resin did not have significant effects on the boards' internal bond strength (Figure 5) even though some increments were observed (in boards A, B and C bonded with MUF-based resin). Only boards D (100% core) and E (control) achieved > 0.8 MPa. Interestingly, almost all boards reduced their

Table 2 Per cent improvement in MOE, MOR and IB of kenaf board after pretreatment with low molecular weight PF resin

Type of board	Improvement in properties (%)					
	UF-based			MUF-based		
	MOE	MOR	IB	MOE	MOR	IB
A	14.0	46.2	-36.4	6.4	8.8	109.1
B	28.0	17.8	0	20.6	17.1	100
C	-0.8	-9.0	-81.3	-22.0	-16.3	44.4
D	11.4	2.6	-4.8	32.3	11.8	-43.3
E	-0.1	4.5	-1.1	0	5.3	-1.2

A 30% core:40% bast:30% core B 35% core:30% bast:35% core
C 40% core: 20% bast:40% core D 100% kenaf core
E 100% rubberwood (control)

bonding strength once treated with LPF resin (Table 2). There was distinctly poor fibre bonding in all the multi-layered boards, in particular those containing 40% bast fibres. As shown in Figure 5, boards constituting 100% kenaf core were superior in internal bond (IB) strength (1.20 MPa), exceeding that of 100% rubberwood (0.82 MPa). Almost all the failures observed in the IB specimens originated from the middle of the board where the bast fibres were located. Some of the cured resins were seen retained on the fibre surfaces, indicating insufficient penetration of the resin. There were also areas on the fibre surfaces without any trace of resin adhesive. The lack of inter-fibre bonding was responsible for the low IB strength in all boards comprising kenaf bast. The interaction effect between resin type and proportion of core to bast was clearly seen in this study, whereby multi-layered boards were found acceptably superior (high stiffness, strength and internal bond strength) when a combination of LPF and UF resins was used.

Even though the main purpose of pretreating the particles/fibres with LPF resin is to improve the dimensional stability of the resulting boards, the results of thickness swelling and water absorption gathered from this study did not verify this. It is a well known fact that impregnation of resin, particularly phenolic type, into wood cells followed by *in situ* polymerization would enhance the wood's dimensional stability, hardness, mechanical strength and resistance to fungi and weathering (Imamura *et al.* 1998, Gindl *et al.* 2003, Furuno *et al.* 2004). In this study, a combination of LPF with UF and MUF resins had marginal effects on the stability of the kenaf board. Even though MUF–LPF bonded boards experienced a slight improvement in both thickness swelling (TS) and water absorption (WA), boards bonded with LPF–UF did not show any marked improvement. As indicated in Figure 6, the most stable was board D (100% core), TS being 7.3%, followed by board E (control), 11.8%. Since kenaf core is very absorbent, such improvement is expected due to the enhancement in the core material itself as a result of crosslinking with phenolic resin. The study also suggests that LPF can be used to improve the TS but it will only work for core particles. The results of water absorption (WA) in Figure 7 showed that there was relatively high absorption after 24 hours of soaking in water, with values ranging from 95–131%.

CONCLUSIONS

Kenaf bast, kenaf core and rubberwood were apparently less sensitive when exposed to alkaline environment. Under alkaline condition, the buffering capacity of rubberwood was between kenaf bast and core. Conversely, both the kenaf bast and core were relatively more sensitive to acid compared with rubberwood. Due to its morphological characteristics, kenaf core inner surface exhibited higher wettability than the outer surfaces. Multi-layered kenaf boards comprising bast materials in the middle layer were poorer in performance than that of homogeneous boards from 100% kenaf core and from 100% rubberwood. The apparent lack of inter-particle

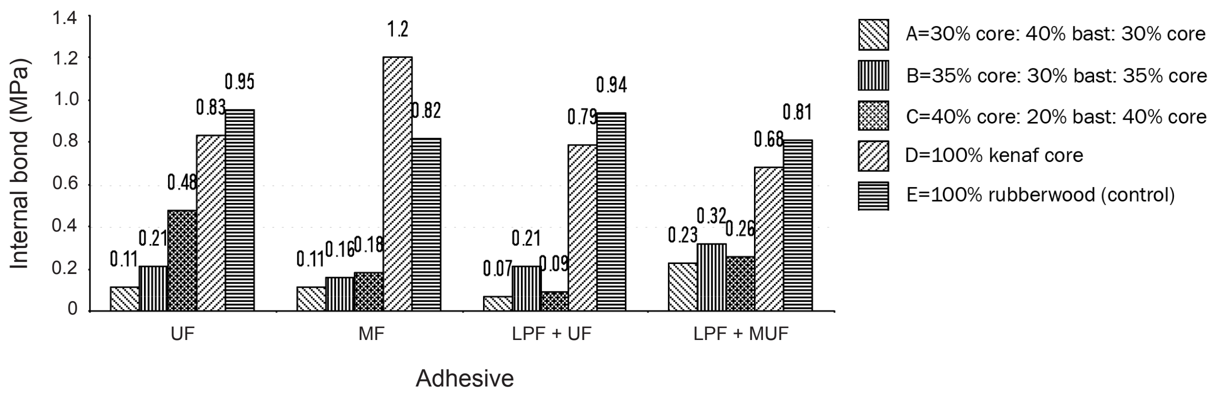

Figure 5 Internal bonding (IB) of kenaf board bonded with different types of resins

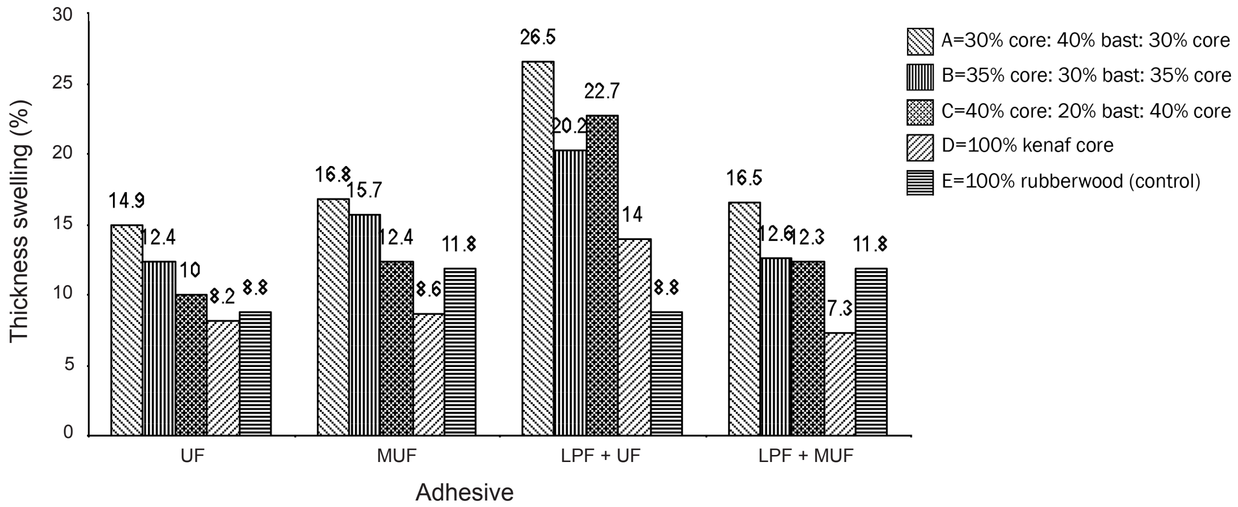

Figure 6 Thickness swelling (TS) of kenaf board bonded with different types of resins

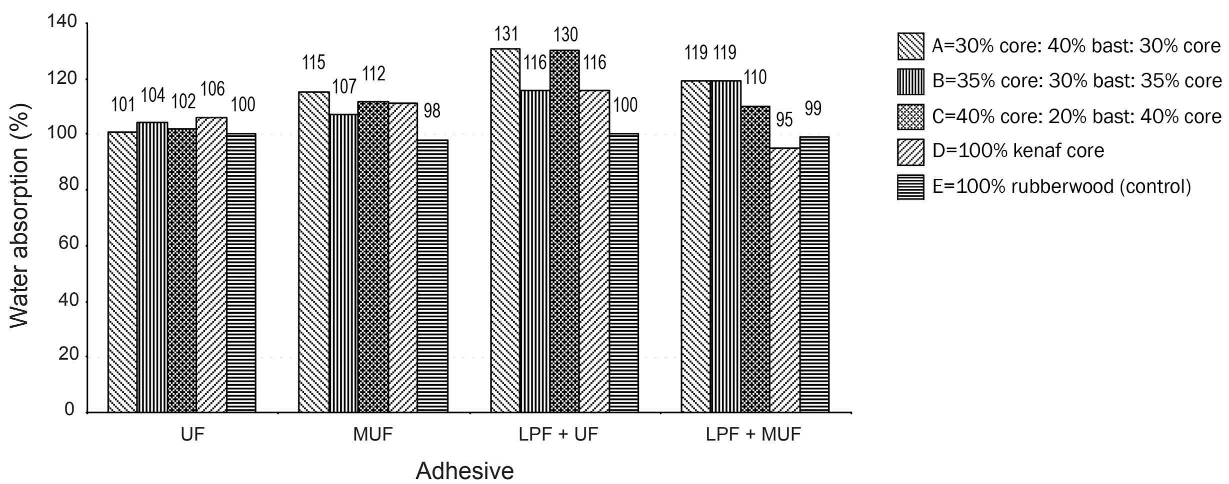

Figure 7 Water absorption (WA) of kenaf board bonded with different types of resins

bonding within the bast fibres is the reason for the inferior properties. All kenaf boards in this study, however, had comparable, if not higher MOR than that of 100% rubberwood. The incorporation of LPF resin in the particles/fibres had mixed influence on the board's properties. The effects can be divided into two: (1) when used with UF resin, it improved the MOE and MOR of the board but not the IB, TS and WA (2) when used with MUF resin, it improved only the IB. The best performance was given by boards made from 100% kenaf core irrespective of the type of resin used. Insufficient curing of LPF resin was identified as the main factor for the poor performance of LPF-bonded boards.

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