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PRODUCTION OF HIGH-PERFORMANCE LOW DENSITY FIBREBOARD FROM CO-REFINED RUBBERWOOD-KENAF CORE FIBRES

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A 50:50 kenaf core to rubberwood ratio were used to fabricate low-density fibreboards. Firstly, the fibres were co-refined at 180 °C for 10 min. Refined fibres were sieved on six levels of size distribution. Results on fibre size distribution concluded that the co-refined fibres were similar in size, in comparison to commercial rubberwood fibres. Low-density fibreboards were fabricated using the admixture of both rubberwood and kenaf core fibres. The results showed that board density played a greater role in producing high quality lightweight fibreboard rather than resin content. The study also revealed that low density fibreboards with acceptable properties could be successfully produced. Low-density fibreboards (550 kg m^{-3}) had comparable physical and mechanical properties to those of commercial MDF (720 kg m^{-3}). Nevertheless, a slightly higher resin content of 14% is needed, in comparison to the commercial MDF. Combining kenaf core and rubberwood fibres improved the internal bonding strength significantly. A total of 80% of the low-density fibreboards produced in this study passed the British Standard 622-5: 2009 even at a board density as low as 350 kg m^{-3}.

Keywords: Light density fibreboard, rubberwood, kenaf core, physical, mechanical

INTRODUCTION

Medium density fibreboard (MDF) typically has a density ranged from 600–800 kg m^{-3}. There are numerous approaches of producing lightweight fibreboard to save weight, as well as to reduce the costs of raw materials and energy consumption. As stated by Monteiro et al. (2018), light and ultra-light MDF are manufactured in the same way as MDF, but at lower pressing pressure to attain lower density of the panel. This type of panel is used in situations where weight reduction is required in the range of 15–20% and where the machinability performance is not a limiting factor. Apart of applying lower pressing pressure, low density material can be used to produce lightweight MDF. However, most wood species have a density much higher than 300 kg m^{-3}, thus causing issues to produce fibreboard with a density lower than 200 kg m^{-3} (Xie et al. 2011). To make low-density fibreboards, wood must essentially be from those species of low density, i.e < 300 kg m^{-3}. Malaysia and other ASEAN countries use rubberwood because of its availability and relatively cheap price. Nevertheless, because of its density (550–580 kg m^{-3}), it is impossible to produce low density fibreboard using 100% rubberwood. Thus, another low-density lignocellulosic material such as kenaf core (100 kg m^{-3}) is needed for mixing with rubberwood. By doing so rubberwood will retain the strength of the board whilst kenaf core will provide the compactness and good internal bond to the board.

Kenaf, *Hibiscus cannabinus*, has been reported to have excellent properties for MDF, and other composites, as it has a low density, little abrasion during processing, high filling levels and high specific mechanical properties (Neyari et al. 2014). Currently, MDF plants use mainly rubberwood with a density of 550–580 kg m^{-3}. Producing a fibreboard of less than 600 kg m^{-3} density using rubberwood alone is quite impossible. Therefore, it is anticipated that a combination of rubberwood and kenaf core would result in lighter yet stronger fibreboard. On that account, low density lignocellulosic material such as kenaf could be a potential raw material for the manufacturing of lightweight fibreboard. In a previous study, the fabrication of low-density fibreboard (100 kg m^{-3}) using light material from 100% kenaf core was found to be still too poor to satisfy the mechanical test requirements (Xu et al. 2004). Therefore, it is anticipated that the admixture of woody material such as rubberwood is necessary to improve the mechanical properties of the lightweight fibreboard.

Kenaf core is abundantly available as a by-product of kenaf processing mills. Because of its low density, kenaf core has limited usage. Any effort to develop products from it would help make kenaf industries more competitive. The main aim of this study is to evaluate the feasibility of kenaf core as raw material for the production of admixture rubberwood-kenaf core low-density fibreboard. The specific objectives were to determine the effect of resin levels and board density (350 kg m^{-3}, 450 kg m^{-3}, 550 kg m^{-3}) on physical (water absorption, thickness swelling and density) and mechanical (modulus of elasticity, modulus of rupture and internal bonding) properties of dry-formed light weight fibreboard.

MATERIALS AND METHOD

Preparation of fibre

Rubberwood and kenaf core were used in the preparation of low density fibreboard (LDF). Rubberwood chips were obtained from a local MDF plant. The moisture content (MC) of the rubberwood chips was about 14%. Kenaf core was obtained from Rompin, Pahang, Malaysia, and chipped to smaller size. Both kenaf core and rubberwood were refined using a thermo-mechanical pulping. The pressurised refiner had a maximum capacity of 280 liter and equipped with 30 cm diameter refiner disc. The fibres were refined under temperature 180 °C and pressure 10 bars. The fibres were refined using a ratio of 50% kenaf core to 50% rubberwood with a refining time of 10 min.

Fibre distribution and morphology study

In fibre distribution study, 4 classes of mesh size, namely 1, 0.4 , 0.2 and 0.125 mm were sampled. These four sizes were based on MDF plants for the determination of fibre size distribution. Fibres of kenaf core and rubberwood from each size were randomly selected to observe the morphology of the fibres. Sampling of fibre for morphology analysis was based on two fibre classes that had the highest fibre yield. The observed fibre morphology included length, width and aspect ratio of kenaf core and rubberwood, using digital image analyser. Fibre distribution trend was then established by plotting the percentage of fibre against fibre size for each treatment parameter. Samples of refined rubberwood fibres from a local MDF factory was taken and classified into size class for comparison.

Production of medium density fibreboard

A local MDF plant supplied urea-formaldehyde (UF) resin (60% solid). The co-refined fibres were mixed with 10, 12 and 14% UF resin, based on oven-dried weight of the particles, using a blender. The fibre and resin were mixed for 5 min. After blending, the furnish was removed from the blender and placed into a 300 × 300 mm former where caul plates were placed at the bottom of the pre-formed board. Teflon release paper was inserted between the hot press and the surface of the furnish. The furnishes were then pre-pressed using a cold press for 10 min at minimal pressure to ensure trapped air evaporation, to reduce the possibility of blow due to entrapped hot air. Following this, the fibres were pressed using 30 ton hot-press at Malaysian Palm Oil Board (MPOB) for 6 min at 180 °C. The lightweight board were conditioned until a constant weight was achieved. A total of 27 boards (three per variant) of 300 × 300 × 9 mm were produced.

Physical and mechanical properties evaluation

The conditioned board were tested according to British Standard 622-5: 2009. The boards were cut to test specimen sizes: 300 mm length × 50 mm width for static bending test, and 50 mm length × 50 mm width for internal bond, water absorption and thickness swelling test. The water absorption and thickness swelling were determined after immersing the sample in water maintained at 20 °C for 24 h. A total of five samples per variant were tested for each property. For comparison, commercial MDF boards of density between 700–750 kg m^{-3} were obtained from a local MDF plant. The boards were tested using the same method described earlier.

Data analysis

The data was analysed by ANOVA using SPSS software. The data was further analysed by using Least Significance Difference (LSD). The LSD is used to compare means of one group with another, ranking them according to their significance; means followed by the same letter (a, b, c, d) are not significantly different at $p \leq 0.05$.

RESULTS AND DISCUSSION

Fibre distribution and morphology

Figure 1 exhibits the fibre distribution of rubberwood and kenaf core after 10 min of refining. It is interesting to note that irrespective of kenaf core:rubberwood ratio or refining time, a similar trend of fibre size distribution can be determined, which fit well with that of commercial refined rubberwood fibres. This indicates that the refining parameters used in this study are able to produce fibres of comparable quality as of commercial fibres. The combination of kenaf core and rubberwood under a single refining process produced fibres mainly retained at mesh sizes 0.4 mm (~40%) and < 0.125 mm (30%). The evaluation of fibre morphology is based on fibres that were taken from < 0.125 mm (very fine) and 0.4 mm (fine to moderate) classes. These classes represented about 70% of the whole fibres. The following discussion is based on the above analysis of these fibres.

Table 1 displays the fibre morphology as function of kenaf core:rubberwood ratios. For fibres at class < 0.125 mm, rubberwood had significantly longer fibres compared to kenaf core. As the amount of rubberwood decreased, the average fibre length also decreased markedly. Apart from that, rubberwood had significantly narrower fibre width compared to kenaf core, hence the average fibre width increased as more kenaf core were added. The aspect ratio (AR) of the fibres decreased as the amount of rubberwood increased. On the other hand, 0.4 mm class fibres contained kenaf core and rubberwood fibres of about the same length. It can also be noted that most of the fibres in this class were in bundles rather than single fibres. Therefore, the average width of the fibre is much larger. The AR for fibre under 0.4 mm class was slightly lower than that in the < 0.125 mm class. The 50 kenaf core:50 rubberwood had AR in between of 100 kenaf core and 100 rubberwood, and therefore it is anticipated to be able to offset the drawbacks of kenaf core.

Mechanical properties

The summary of ANOVA for the effect of board density and resin level on board properties are presented in Table 2. The table shows that density exerted significant influence on the bending strength of the boards, while the internal bond of the boards was more affected by resin level. Modulus of rupture (MOR) and modulus of elasticity (MOE) of the fibreboards made with different densities and resin levels are displayed

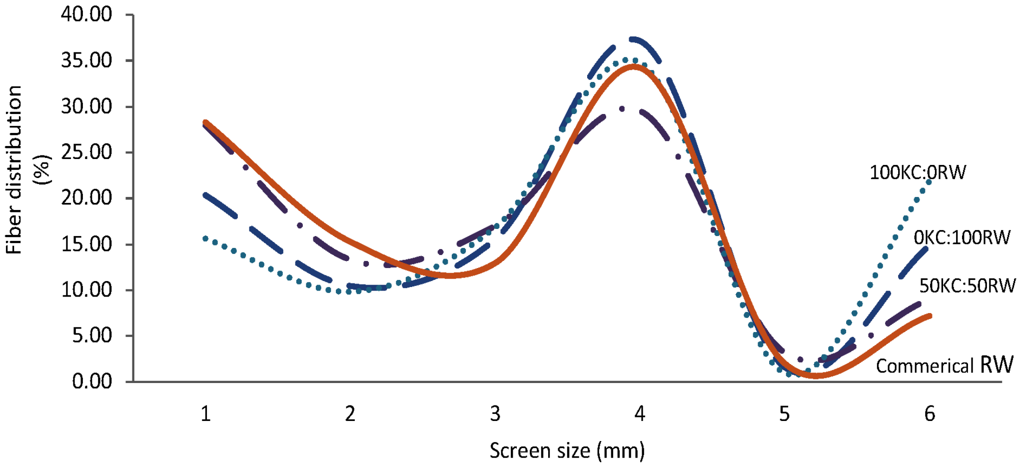

Figure 1 Fibre distribution after 10 min refining of kenaf core (KC) and rubberwood (RW) at different ratios
Note: Screen size (mm) 1 = < 0.125, 2 = 0.125, 3 = 0.2, 4 = 0.4, 5 = 1.0, and 6 = 2.0

Table 1 Effect of kenaf (KC):rubberwood (RW) ratios on fibre morphology

Properties	Class < 0.125mm			Class 0.4mm		
	0 KC: 100 RW	50 KC: 50 RW	100 KC: 0 RW	0 KC: 100 RW	50 KC: 50 RW	100 KC: 0 RW
Length (μm)	1142.08	941.14	773.75	2157.39	2974.30	2744.44
Width (μm)	20.68	25.74	28.78	62.23	140.97	132.31
Aspect ratio	56.34	40.15	27.36	36.88	27.40	21.69

Table 2 Summary of ANOVA on the effect of board density and resin content on the mechanical properties of lightweight fibreboard samples

Source	DF	MOR	MOE	Internal bond
Density	2	***	***	*
Resin Content	2	ns	ns	**
Density*Resin Content	4	ns	ns	***

***significant at $p \leq 0.01$, **significant at $p \leq 0.05$, *significant at $p \leq 0.1$, ns = not significant at $p > 0.1$, DF = degree of freedom, MOR = modulus of rupture, MOE = modulus of elasticity

in Figure 2 and Figure 3, respectively. It can be observed from the figures that both MOR and MOE were significantly affected by board density, where the bending strength of LDF increased along with increasing density. In BS EN 622-5, there are two types of ultra-light MDF for dry conditions, namely UL1-MDF and UL2-MDF. The former was typically used as insulation panel providing limited mechanical stiffness, while the latter was typically used as panels with stiffening function, able to be used with fasteners and having insulating properties. The results revealed that LDF having density of 450 kg m^{-3} and 550 kg m^{-3} exceeded the minimum requirement for MOR stated in BS EN 622-5: (2009) type UL1-MDF, which is 7.7 MPa. On the other hand, LDF with all density levels met the minimum requirement for MOE (600 MPa) as specified in BS EN 622-5. It is interesting to note that all the LDF with 550 kg m^{-3} had higher MOR, MOE and IB than commercial MDF boards with 720 kg m^{-3}.

The highest mean MOR was given by LDF with a density of 550 kg m^{-3} which was 25.7 MPa. According to Xu & Suchsland (1998) the bending properties of mix species composite boards were less than single species counterpart. During mixing, lighter density fibres have the tendency to flow on top of the mixing tank, hence absorbing more resin than the heavy fibres. Short length fibres have low AR, resulting a reduction of MOR and MOE value. According to Ayrilmis & Buyuksari (2010), MOR and MOE values increase due to the fact that longer fibres have an increased network system by themselves, resulting in increased bending properties of fibreboard. Similar results were observed by Aisyah et al. (2013). Where the MOR and MOE values increase due to thinner fibres which consequently make the mat easily compressed, thus giving better compaction. Furthermore, fine fibres (i.e. fine fibrils gap filling material) fill the gaps between fibres.

The internal bonding (IB) of LDF produced in this study showed inconsistent pattern, as illustrated in Figure 4. However, all the boards surpassed the minimum requirements of IB strength for UL1-MDF, which is 0.15 MPa. Some of the boards even surpassed the minimum requirements of internal bond strength for UL2-MDF, which is 0.35 MPa. The density of boards was found to be greatly affected by the mechanical properties of the boards. Higher density contained more wood per unit volume; greater amounts of wood substance were compacted to form a board and bring higher mechanical properties to the fibreboard. Addition of resin usage brought positive effect to MOR value in both density levels. Greater additions of resin translated into a board of enhanced properties. Increasing resin content appeared to increase internal bond strength in a linear fashion. Higher density contained more wood per unit volume, where greater amounts of wood substance were compacted to form a board

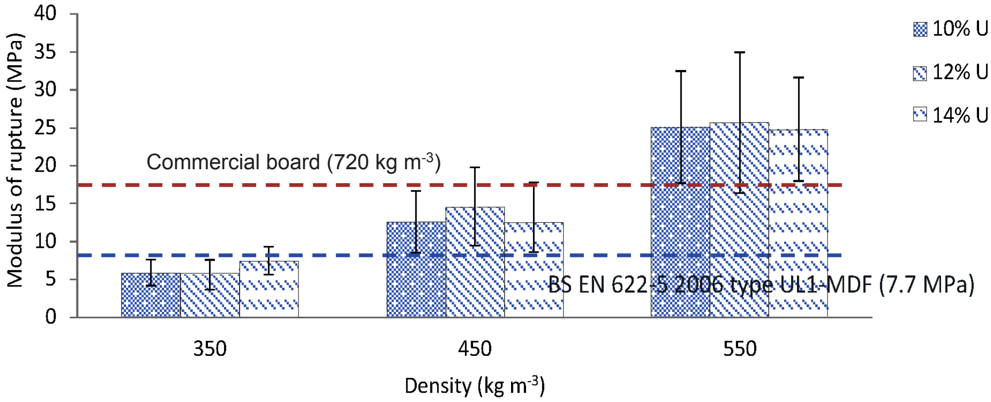

Figure 2 Modulus of rupture of lightweight fibreboard manufactured from co-refined rubberwood-kenaf core bonded with different loadings of urea formaldehyde (UF) resin

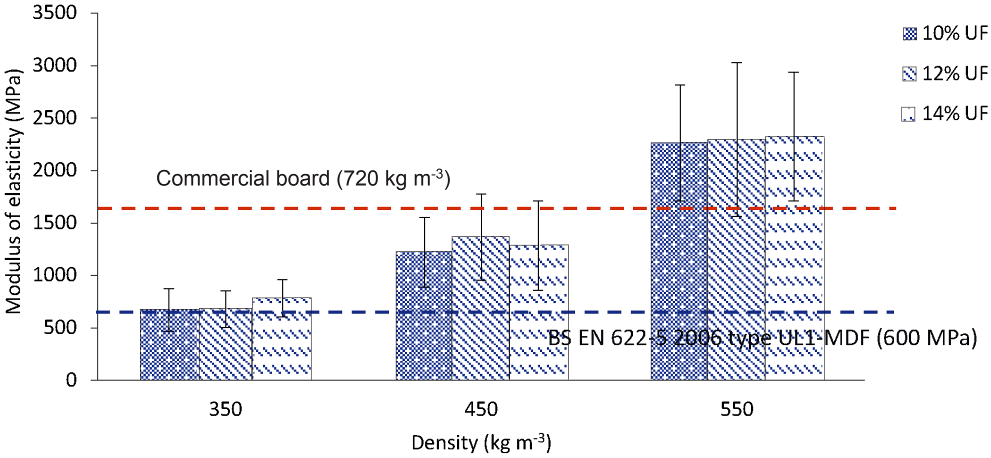

Figure 3 Modulus of elasticity of lightweight fibreboard manufactured from co-refined rubberwood-kenaf core bonded with different loadings of urea formaldehyde (UF) resin

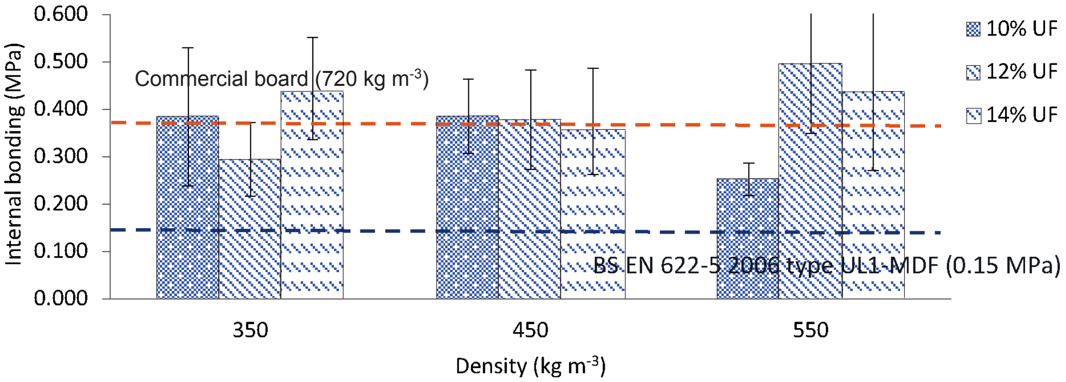

Figure 4 Internal bonding of lightweight fibreboard manufactured from co-refined rubberwood-kenaf core bonded with different loadings of urea formaldehyde (UF) resin

and bring higher mechanical properties to the particleboard.

Physical properties

The result of ANOVA for physical properties, including water absorption and thickness swelling test, are summarised in Table 3. It was observed that board density had a significant effect on both water absorption and thickness swelling of LDF. Meanwhile, it was found that the resin content only affected the thickness swelling of LDF. Figure 5 shows that the water absorption of LDF decreased along with increasing board density and resin content. Samples having a board density of 550 kg m^{-3} at 14% resin content showed the lowest percentage of water absorption. This phenomenon may be explained by the theory of void over volume of board. Greater existence of voids found in low-density particleboards may provide spaces that encourage penetration of water, leading to higher water absorption (Loh et al. 2010). Figure 6 shows that the percentage of thickness swelling decreased with increasing resin content. Nevertheless, as the board density increased, the thickness swelling also increased. It was observed that almost all the samples, with exception of LDF made with 10% resin content and 550 kg m^{-3}, met the requirement of BS EN 622:5 (2009) type UL1-MDF with a maximum allowable thickness swelling of 18%.

Gatchell et al. (1966) concluded that the resin level is the most important single variable for controlling swelling of particleboards. Turner (1954) also proved the significance of resin level for improving thickness swelling. Greater additions of resin translate into a board of enhanced properties, particularly its thickness stability. Moslemi (1974) reported that higher density boards swell more when exposed to water for sufficient time. Lower density panels exhibit less swelling for two probable reasons: first, they contain less wood per unit volume with the ensuing swelling partially extending into interparticle voids, and second, the presence of a smaller volume of wood per unit area which means a lower degree of hygroscopic response. High thickness

Table 3 Summary of ANOVA on the physical properties of lightweight fibreboard samples

Source	DF	WA	TS
Density	2	***	***
Resin Content	2	n.s	***
Density*Resin Content	4	n.s	n.s

***significant at $p \leq 0.01$, **significant at $p \leq 0.05$, *significant at $p \leq 0.1$, ns = not significant at $p \leq 0.1$, DF = degree of freedom, WA = water absorption, TS = thickness swelling

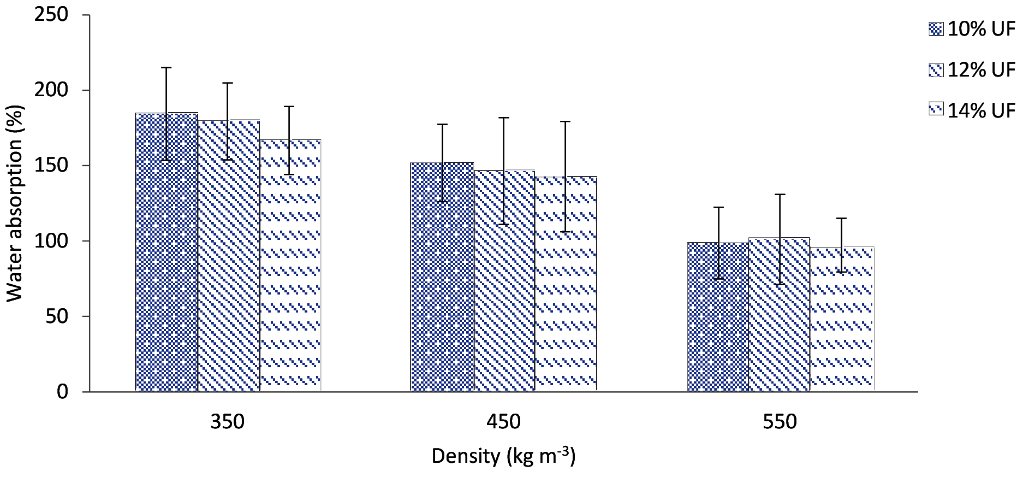

Figure 5 Water absorption of lightweight fibreboard manufactured from co-refined rubberwood-kenaf core bonded with different loadings of urea formaldehyde (UF) resin

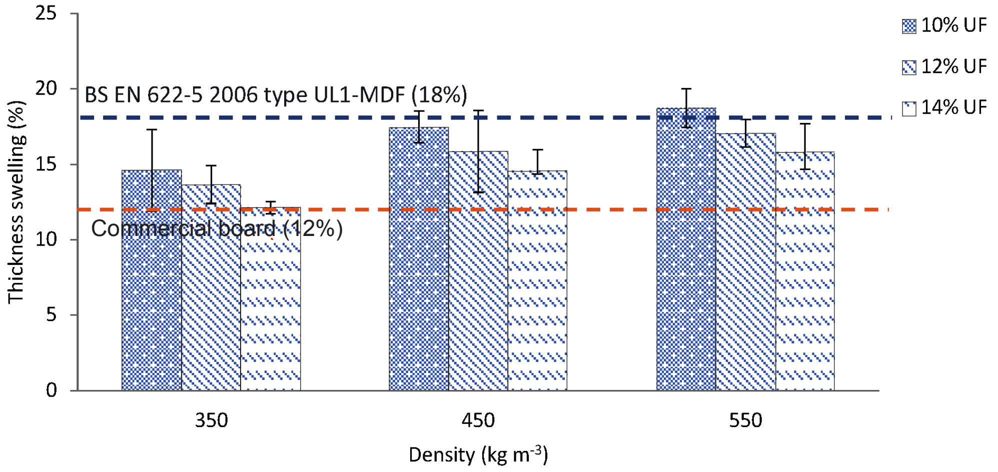

Figure 6 Thickness swelling of lightweight fibreboard manufactured from co-refined rubberwood-kenaf core bonded with different loadings of urea formaldehyde (UF) resin

swelling value is very common in the high density boards. Khedari et al. (2003) found an increase in thickness swelling with increasing density of particleboard. Compression stress is another reason that causes higher thickness swelling, occurring in boards with higher density. For a particular wood raw material, the compression needed for particleboard pressing operation increases as desired board density increases. Thus, there is a higher compression set in higher density boards, and these would be expected to give higher swelling as stresses are relieved (Gatchell et al. 1966).

CONCLUSION

The study showed that using 50 kenaf core:50 rubberwood ratio and 10 min refining time, suitable fibres could be produced for fibreboard manufacturing. A well distributed fibre size was successfully obtained, which is analogous to that of commercially refined rubberwood. The result showed that board density played a greater role in producing high quality lightweight fibreboard rather than resin content. The study showed that low-density fibreboards (550 kg m^{-3}) of superior properties, comparable to those of commercial MDF (720 kg m^{-3}), could be produced using co-refined kenaf core-rubbewood fibres at 50:50 ratios. Nevertheless, a slightly higher resin content of 14% is needed. The 80% of the LDF produced in this study passed the standards of BS EN 622-5, even at a board density as low as 350 kg m^{-3}.

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