Advances in Research
3(5): 502-511, 2015, Article no.AIR.2015.046
ISSN: 2348-0394

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Hybrid Particleboard from Wood and Non-Wood Species: Physical and Mechanical Properties as a Function of Particle Mixing Ratio

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Authors' contributions

This work was carried out in collaboration between all authors. Authors MAWH and MAI designed the study, Authors MAWH and SBR performed the experimental study, and authors TI and KSR wrote the first draft of the manuscript. Author AS managed the literature searches, and authors KSR and AS managed the analysis of data and Authors KSR, MAI and MNI wrote the final manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2015/14229
Editor(s):
(1) Yan Juan, Biotechnology Breeding, Sichuan Agricultural University, Ya'an, China.
Reviewers:
(1) Marina Stojanovska, Department of Chemistry, Faculty of Natural Sciences and Mathematics, Ss Cyril and Methodius University, Skopje, Republic of Macedonia.
(2) Anonymous, University of Education, Winneba, Kumasi Campus, Ghana.
(3) Anonymous, Bogor Agricultural University, Indonesia.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=757&id=31&aid=7099

Original Research Article

Received 23rd September 2014
Accepted 20th October 2014
Published 6th December 2014

ABSTRACT

Aims: In this paper three-layer hybrid particleboard was fabricated from kadam (*Anthocephalus chinensis*) and kenaf (*Hibiscus cannabinus L.*) as a function of particle mixing ratio based on oven dried weight.
Experimental: Three types of three-layer hybrid particleboards i.e., HB_{PB}-A (Fine: kenaf; coarse: kadam), HB_{PB}-B (Fine: kadam; coarse: kenaf), HB_{PB}-C (kadam and kenaf mixed); and two types of control particleboard i.e., C_{PB}-D (kadam) and C_{PB}-E (kenaf) were fabricated with 10% urea formaldehyde resin. The effects of particle ratio on the physical and mechanical properties of new hybrid particleboards were investigated according to the procedure of ASTM D-1037 standard.
Results: It was found that the particle ratio within and/or between layers showed significant effects on the physical and mechanical properties of the hybrid particleboards. It was also observed that

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hybrid particleboard HB_{PB}-C with the ratio of kadam: Kenaf(50:50) exhibited the highest mechanical properties i.e. modulus of elasticity and modulus of rupture and physical properties i.e. density, moisture content, water absorption and thickness swelling, compared to HB_{PB}-A (kenaf: kadam-40:60) and HB_{PB}-B (kadam: kenaf-40:60) hybrid particleboards. HB_{PB}-C also showed higher physical and mechanical properties compared to the C_{PB}-E, however, it was lower than the C_{PB}-D.
Conclusion: The results confirmed that HB_{PB}-C and HB_{PB}-B particleboard met the minimum ANSI A208.1 requirements for physical and mechanical properties of M-3 grade particleboard. Thus, such kind of hybrid particleboard is technically feasible.

Keywords: Anthocephalus chinensis; Hibiscus cannabinus L.; three layer particleboard; urea formaldehyde (UF) resin.

1. INTRODUCTION

Particleboard is a panel manufactured by compressing particles i.e., small pieces of lignocellulosic (woody and/or non-woody) materials through simultaneously bonding with adhesives under heat and pressure [1]. Wang and Sun [2] stated that particleboards are mainly used in cabinets, floor, wall, furniture, desk and counter tops, ceiling panels and office dividers. Therefore, the demand of particleboards increases all over the world due to its strength and workability, and is manufactured in great quantities [3] which results in large quantities of lignocellulosic raw materials consumption by the processing industries causing threat to the natural forest as well as to the environment. In addition, shortage of raw materials is mainly due to deforestation and degradation of natural forest and this trend of resource degradation are increasing with crushing population growth [4]. Therefore, most of the particleboard industries in Bangladesh are largely using fast growing species like kadam (*Anthocephalus chinensis*) from plantation for particleboard production [5]. The sapwood of kadam is cream-white colored while the heartwood is of yellowish cast having the density of 426.1 kg/m^3 [5]. Martin et al. [6] reported that the wood of kadam exhibited fine to medium texture, straight grain, and low luster and no significant odor or taste. As a result it becomes one of the major raw materials in particleboard manufacturing which exhibits superior quality particleboards. Kenaf (*Hibiscus cannabinus*) is an annual herbaceous plant which is cultivated in tropical and subtropical regions for its fibres. Presently, kenaf fibers are mainly used for the production of rope and sackcloth, and the stalks are seldom burnt as fuel in the rural areas of Bangladesh. According to Webber and Bledsoe [7] and Juliana et al. [8], kenaf stalks could be a good raw material for the production of particleboards of various densities. It would also reduce the pressure on the forest for the raw materials in particleboard industries.

Fabrication of three layer particleboard normally requires potential combination of particles and/or particle types to have better performance i.e., physical and mechanical properties. In addition, the physical and mechanical properties of particleboards are the key factor to be considered whether the products would be used as structural members or not as it would subject to atmospheric moisture changes and different loads in use. Besides, the properties are largely affected by different raw materials and content, processing parameters, adhesive types and content and also by some environmental factors including temperature, humidity etc. [9]. An extensive literature search did not reveal any information about the fabrication of three layer hybrid particleboard from wood (kadam) and non-wood (kenaf) particles as a function of particle mixing ratio. Thus, the purpose of this study was to investigate the technical feasibility of three layer hybrid particleboard fabricated from kadam (*Anthocephalus chinensis*) trunk and kenaf (*Hibiscus cannabinus* L.) stalks as a function of wood and non-wood particle mixing ratio.

2. EXPERIMENTAL

2.1 Materials Preparation

Matured (6 month old) kenaf stalks and kadam tree (7 years old with 12.5 m height and 25.2 cm diameter) were collected from Gopalgonj and Khulna District of Bangladesh, respectively. The debarked kadam lumber and kenaf stalks were chipped in a laboratory chipper and later a laboratory grinder was used to convert it into particles. The particles were screened through 8 and 2 mm screen to separate the coarse and fine particles as well as to remove the impurities. The particles were then dried to 3% moisture content (MC) in an oven with 103±2°C temperature for 24 hours. The fine and coarse particles were used in the face and core of particleboard, respectively.

2.2 Particleboard Fabrication

Coarse and fine particles of kenaf and kadam were separately blended with 10% (based on the oven dry weight of particle) commercial grade liquid urea formaldehyde (UF) resin having the solid content of 48% by using a drum type blender [3]. The particles were then shifted to the forming box for mat formation and it was done by hand lay-up method. Table 1 illustrates the percentage (on weight basis) of fine and coarse particles in the face (top), core and face (bottom) layer was 20, 60 and 20%, respectively according to Rahman et al. [3]. Mat thickness was maintained at least thrice of the target thickness of particleboard (8 mm). The mats were then manually pre-pressed to facilitate the easy insertion of mats into the hot press. All mats were hot pressed for 5 minutes at specific pressure of 5.38 N/mm^2 and temperature of 160°C to produce 8 mm thick particleboards [10] by using electrically heated hot press (DZ47-63, D32). Three types of hybrid and two type of control particleboard were fabricated according to the formulation given in Table 1. At least, three replication of each type board was fabricated and having the dimension of 30×25×0.8 cm. The boards were then trimmed, sanded and kept in the conditioning room for 48 hrs. According to the ASTM standard D-1037 [11], all specimens were carefully prepared and tested to evaluate the physical and mechanical properties for each type of board. At least six (6) specimens for each property were prepared from each type of board.

2.3 Physical Properties Evaluation

Six (6) specimens having the dimension of 50×50×8 mm were used to evaluate the physical properties including density, moisture content (MC), water absorption (WA) and thickness swelling (TS) by following the standard ASTM D-1037 [11] for wood-based composites. Moisture content was measured by the oven dry method. Two and 24 hrs water soaking test determined the water absorption behavior of the panels having the same dimension of samples. The water absorption and thickness swelling was measured by the difference in weight and thickness of the samples, respectively before and after 2 and 24 hrs of immersion in water [3].

2.4 Mechanical Properties Evaluation

Modulus of elasticity (MOE) and modulus of rupture (MOR) were measured following the three point bending test by using universal testing machine (IMAL-IB600) according to the ASTM D 1037-93 standard [11]. Particleboards were cut into rectangular sections for determining the MOE and MOR. The dimension of each particleboard sample was 240×50× 8 mm.

2.5 Statistical Analysis

Completely randomized design (CRD) was used for the experiment. Statistical analysis was performed by using the MS office excel 2007 and statistical analysis system (SAS) software (version 6.2) at 95% confidence level. The significance of different treatments was determined by variance analysis (ANOVA) and least significant difference (LSD) test (α ≤ 0.05).

3. RESULTS AND DISCUSSION

3.1 Physical Properties

The most important indicator of composite's performance is density, which basically affects all the properties of composites. The values of density of hybrid and control particleboards are illustrated in Fig 1.

Table 1. The raw material formulation for three layer particleboards

Panel types	Formulation	Top (face)	Core	Bottom (face)
		Fine particles (%)	Coarse particles(%)	Fine particles(%)
HB_{PB}-A	Kenaf	20	-	20
	Kadam	-	60	-
HB_{PB}-B	Kadam	20	-	20
	Kenaf	-	60	-
HB_{PB}-C	Kenaf	10	30	10
	Kadam	10	30	10
C_{PB}-D	Kadam only	20	60	20
C_{PB}-E	Kenaf only	20	60	20

The results showed that the density of hybrid particleboards were lower than the control particleboard (C_{PB}-D) but higher than the C_{PB}-E using the same condition which was related to the density of the raw materials. This might be due to the raw materials density i.e., density of kadam is 426 kg/m^3 [5] whereas kenaf is 290 kg/m^3 [12]; as well as the difference in the percentage of kenaf and kadam particles within and between the layers of the particleboards. In addition, the lowest density indicated the presence of void space or micro cracks present in the composites. Similar results were reported by Abdul Khalil [13]. Moreover, the density of hybrid particleboards except HB_{PB}-A satisfied the requirements for the medium density particleboard according to ANSI [14]. Statistical analysis also illustrated significant difference of density among the five types of three layer particleboard (Table 2). It was also observed that among the hybrid particleboards, HB_{PB}-C fabricated from 60% coarse and 40% fine mixed particles of kadam and kenaf showed density of 646.47 kg/m^3 which is significantly higher than the density of HB_{PB}-A and HB_{PB}-B. Thus, the results reflected the variation of density of particleboards because of the variation of density of raw materials, as the others parameter remains constant. All the hybrid particleboard showed slightly lower density compared to the commercially available particleboard produced from *Alstonia scholaris*, *Bombax ceiba* and mixed particles of *A. scholaris, B. ceiba* and *A. chinensis* as reported by Ashaduzzaman and Sharmin [5].

Fig. 2 illustrates the moisture content of hybrid and control particleboards. Result showed that higher amount of MC found in C_{PB}-E type of control particleboard while C_{PB}-D showed lower moisture content. Moreover, mixing of kadam and kenaf particles (HB_{PB}-C) with 10% UF showed slightly higher MC than C_{PB}-D as well as significantly lower than HB_{PB}-A and HB_{PB}-B types of hybrid particleboards and C_{PB}-E type control particleboard. It may vary due to the differences in hemicelluloses content of raw materials as kenaf contains 21.5% [15] and kadam wood contains 34.5% [16]. The kenaf particles on the outer surface increased the moisture absorption, however, it decreased when mixed with the kadam. Wardrop [17] reported that the increasing hemicelluloses content of lignocellulosic materials increased the moisture absorption of lignocellulosic materials. Franz et al. [18] reported that moisture content of particle board after curing ranged between 8.5 and 11.0%. Except HB_{PB}-A and C_{PB}-E type board, moisture content of all particleboard HB_{PB}-B, HB_{PB}-C and C_{PB}-D comply with the findings of Franz et al.[18]. Based on the statistical analysis significant difference was found for MC values among the particleboards (Table 2).

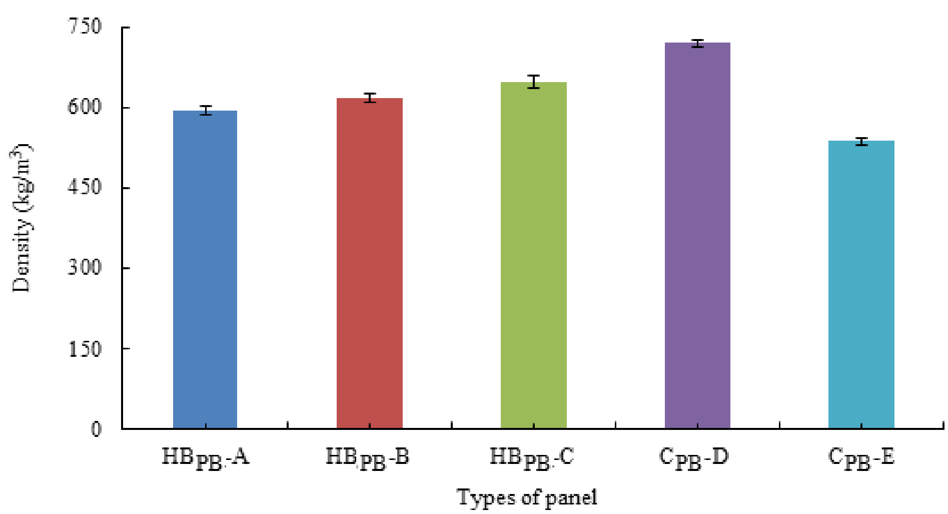

Fig. 1. Density of hybrid and control particleboards

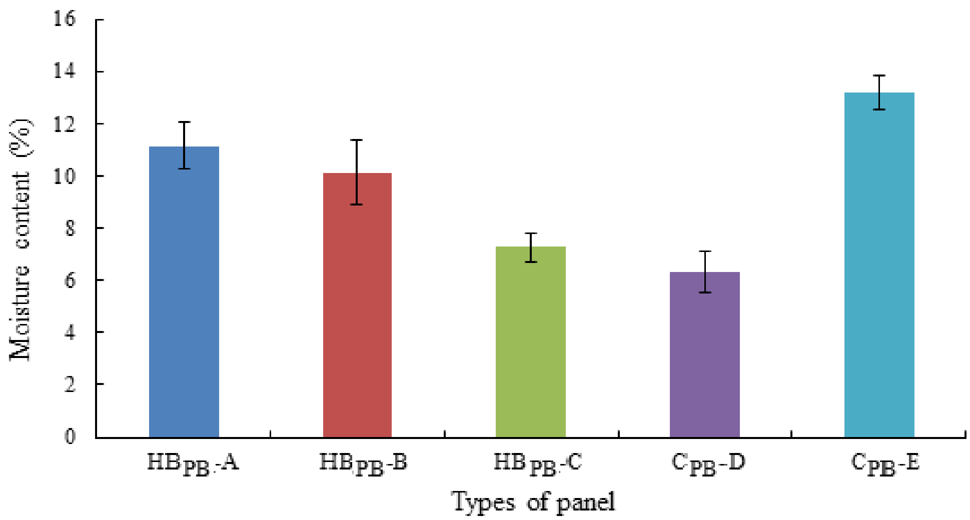

Fig. 2. Moisture content of hybrid and control particleboards

Water absorption of hybrid and control particleboards based on wood and non-wood particle ratio after 2 and 24 hrs of immersion in water are given in Fig. 3. WA of C_{PB}-D and C_{PB}-E particleboards were 18.9 and 23.63%, respectively after 2 hrs and 31.27 and 39.5%, respectively after 24 hrs of immersion in water. Besides these modified effect of WA after 2 and 24 hrs was found for the HB_{PB}-C produced from mixed particles of kadam and kenaf as compared to the C_{PB}-D and C_{PB}-E, respectively. These variations in WA might be attributed to lower hemicelluloses content of kenaf compared to kadam. Due to the presence of free –OH group in the molecular structure, holocellulose especially hemicelluloses are responsible for water absorption as reported by Wardrop [17]. In addition, Skaar [19] found that hygroscopicity of hemicelluloses was higher than the cellulose and lignin. Statistical analysis (ANOVA and LSD) also showed that there was significant difference in WA after 2 and 24 hours among the composites (Table 2). In addition, compared to the commercial particleboard improved resistance of WA was observed for HB_{PB}-A, HB_{PB}-B and HB_{PB}-C hybrid particleboards and the results complied with the results for 24 hrs water soaking test of experimental boards manufactured from *Cassia siamea*, *Dalbergia sissoo*, *Gmelina arborea*, *Meliaazedirach* and *Samanea saman* as reported by Ashaduzzaman and Sharmin [5].

Both raw materials and particleboard density affected the WA after both 2 and 24 hrs of immersion in water (Fig. 3). This variation may occur due to low porosity on the board surface resulting from the higher density made diffusion of water difficult in to C_{PB}-D and HB_{PB}-C particleboard. Moreover, higher density affects correspondingly higher resistant to absorption and swelling properties [18]. Earlier researchers had reported that addition of wax (from 0.5 to 1%) significantly decreased the WA of the boards. The findings of this study are also in agreement with those reported by Biswas et al. [20].

Thickness swelling of both hybrid and control particleboards were determined after 2 and 24 hours and followed the same trend as WA of the particleboards. It was observed that TS of HB_{PB}-B, HB_{PB}-A, C_{PB}-E, HB_{PB}-C and C_{PB}-D particleboards were 29.71, 34.85, 23.28, 20.79 and 17.90%, respectively after 2hrs; and 43.38, 45.29, 39.18, 37.93 and 30.28%, respectively after 24 hrs of immersion in water (Fig 4). Statistical analysis showed significant difference for the TS among the particleboards (Table 2). This variation may occurred due to difference in hemicelluloses content of kenaf (21.5%) [15] and Kadam wood (34.5%) [16] along with the size of raw materials, its ratio, etc. Wardrop [17] reported that responsible factor for hygroscopic nature of lignocellulosic materials was the presence of free –OH group in the molecular structure of cellulose and hemicelluloses and hygroscopicity of hemicelluloses was higher than the cellulose and lignin as it contained higher number of free –OH as reported by Skaar [19]. HB_{PB}-A, HB_{PB}-B, HB_{PB}-C hybrid particleboards showed slightly lower resistance to TS compared to commercial particleboard and experimental boards manufactured from *Cassia siamea*, *Dalbergia sissoo*, *Gmelina arborea*, *Meliaazedirach* and *Samanea saman* as reported by Ashaduzzaman and Sharmin [5]. TS were higher for all hybrid particleboards except HB_{PB}-C type board than for *A. chinensis* and *H. canabinus* particleboards. As far as densities, the result indicated that the TS of HB_{PB}-A and HB_{PB}-B both the hybrid and *H. canabinus* particleboards were higher at 592.29 kg/m^3, 616.66 kg/m^3 and 536.34 kg/m^3.It was also observed that the density of 719.46 kg/m^3 and 646.47 kg/m^3 produced the lowest TS rate. However, the TS rate for the mixed (HB_{PB}-C) hybrid particleboards was higher than the C_{PB}-D type of particleboard, which is lower than the HB_{PB}-A, HB_{PB}-B and C_{PB}-E type of particleboards. The *p*-value (less than 0.0003) indicated that the impact of densities on the TS was significant for hybrid, *A. chinensis* and *H. canabinus* particleboards. The findings of this study were in agreement with those reported by Biswas et al. [20]. The maximum TS after 2 hour of immersion did not exceed 10% of the original thickness as reported by Franz et al. [18]. Thus, the result of this study indicated that raw materials and immersion time had potential influence on the WA of the boards.

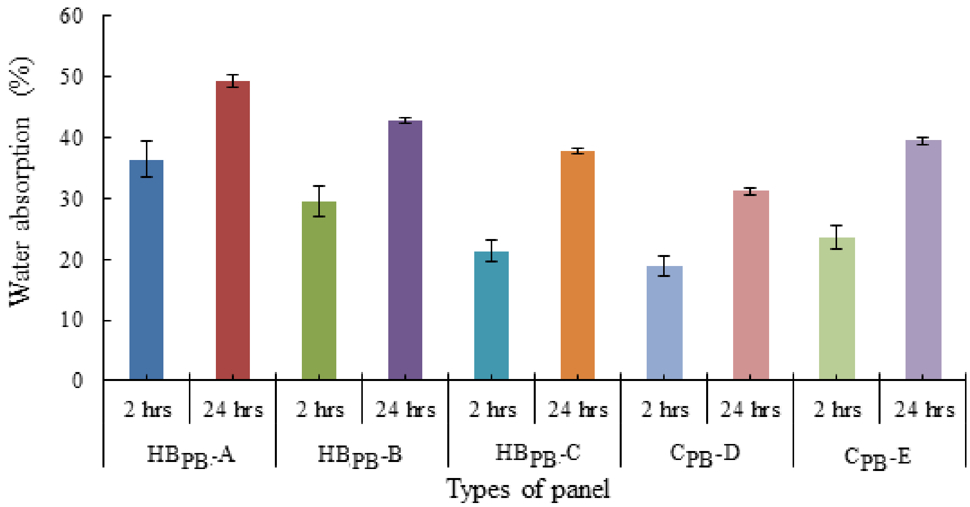

Fig. 3. Water absorption of hybrid and control particleboards after 2 and 24 hour

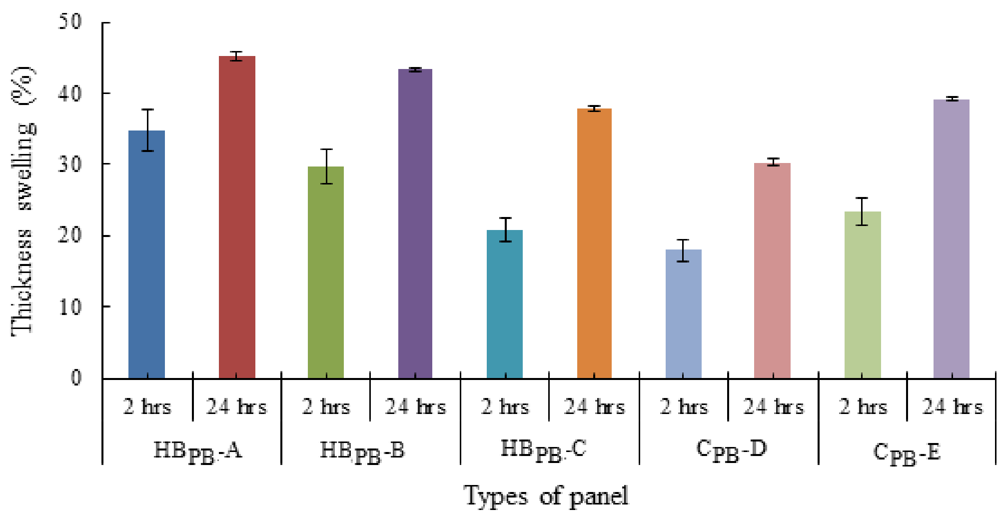

Fig. 4. Thickness swelling of hybrid and control particleboards after 2 and 24 hour

Table 2. Statistical analysis of different properties of hybrid and control particleboards

Panel types	Physical properties						Mechanical properties	
	Density (kg/m^3)	MC (%)	WA (%)		TS (%)		MOE (N/mm^2)	MOR (N/mm^2)
			2 hrs	24 hrs	2 hrs	24 hrs		
HB_{PB}-A	592.29^C (20.68)	11.16^{AB} (2.26)	36.47^A (7.24)	49.30^A (12.10)	34.85^A (6.35)	45.29^A (7.76)	1971.59^{BA} (287.68)	15.59^{BC} (1.28)
HB_{PB}-B	616.66^C (23.19)	10.12^B (2.99)	29.57^{BA} (10.00)	42.82^{BA} (6.40)	29.71^{BA} (2.53)	43.38^{BA} (3.22)	2098.68^{BA} (489.88)	17.00^{BC} (2.98)
HB_{PB}-C	646.47^B (28.18)	7.25^C (1.35)	21.34^C (2.83)	37.88^{BC} (4.66)	20.79^C (4.96)	37.93^B (4.51)	2124.70^{BA} (383.78)	17.80^B (3.47)
C_{PB}-D	719.46^A (17.49)	6.32^C (1.91)	18.85^C (2.81)	31.27^C (6.70)	17.9^C (5.23)	30.28^C (5.91)	2423.35^A (561.38)	22.08^A (5.70)
C_{PB}-E	536.34^D (15.15)	13.17^A (1.57)	23.63^{BC} (5.73)	39.47^{BC} (7.91)	23.28^{BC} (9.22)	39.18^{BA} (3.88)	1674.36^B (226.42)	12.98^C (2.17)

Values in parenthesis are standard deviation

Values within the same line column by different letters are significantly different

3.2 Mechanical Properties

In Fig. 5, MOE of HB_{PB}-A, HB_{PB}-B, HB_{PB}-C, C_{PB}-D and C_{PB}-E particleboards are summarized. Based on the statistical analysis significant difference was determined for the MOE properties of the particleboards (Table 2). MOE of the HB_{PB}-A, HB_{PB}-B, HB_{PB}-C, C_{PB}-D and C_{PB}-E particleboards followed the same trend of density and the order is C_{PB}-D > HB_{PB}-C > HB_{PB}-B > HB_{PB}-A >C_{PB}-E. Among the hybrid particleboard, HB_{PB}-C particleboard showed the highest value for MOE (2124.70 N/mm^2). MOE of HB_{PB}-C was also higher compared to C_{PB}-E (1674.36 N/mm^2) but lower than the C_{PB}-D (2423.35 N/mm^2) (Fig. 5). Therefore, MOE value varied among the different types of particleboard due to the density of raw materials as well as percentage of particle within and between the layers. Franz et al. [18] reported that higher density of raw materials affected correspondingly higher bending strength of manufactured board. Kelly [9] reported similar results for MOE and MOR for particleboards. In addition, lower fiber length of non-wood particle than wood of the stem may be another reason for the lower MOE of C_{PB}-E particleboard [21,22].The HB_{PB}-C hybrid particleboard showed modified MOE properties when compared with the C_{PB}-E and C_{PB}-D particleboards. In another word, the addition of 50% (20% in face and back and 30% in core) non-wood particles in the board formulation to produce HB_{PB}-C increased the MOE properties compared with C_{PB}-E type board. Again, this variation was due to the variation in properties of the raw materials i.e., wood and non-wood particles which modified MOE properties of mixed hybrid particleboards. MOE of HB_{PB}-C particleboard was found to be within the range of ANSI A208.1 requirements for medium density particleboard of M-3 grade.

As shown in Fig. 6, the lowest MOR was found for control particleboard (C_{PB}-E) while the highest MOR was found for control particleboard (C_{PB}-D). Among the hybrid particleboards, HB_{PB}-C produced from 50% kenaf and 50% kadam particles showed the highest MOR value (17.8 N/mm^2) and also possessed modified MOR value compared to C_{PB}-D (22.08 N/mm^2) and C_{PB}-E (12.98 N/mm^2) which may be due to the density and fiber length of raw materials and percentage of particle ratio within and between the layers of the hybrid particleboard. As reported earlier, higher bending strength of fabricated composites results from the high density raw materials [18] and/or increasing board density [9] and also higher fiber length of raw materials [21,22]. Kelly [9] also reported that depending on the surface density, surface particle alignment and adhesive content MOR properties of particleboards varied. Moreover, based on the statistical analysis significant difference was found for the MOR properties of the particleboards (Table 2). The trend of MOR was similar to the trend of MOE for hybrid particleboards and *A. chinensis* and *H. canabinus* particleboards (Fig. 6). The findings of MOR of this study were comparable to the commercial particleboard produced in Bangladesh and much higher than the results of MOR of experimental particleboards as reported by Ashaduzzaman and Sharmin [5].

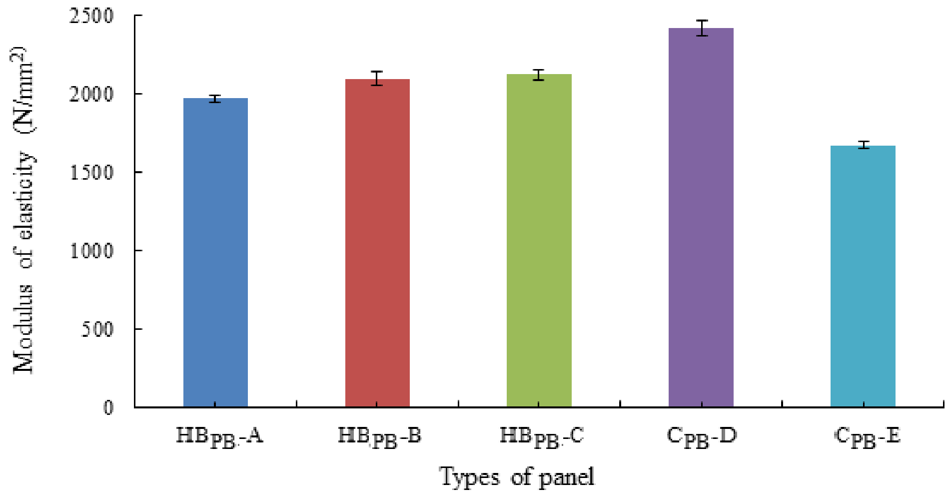

Fig. 5. Modulus of elasticity of hybrid and control particleboards

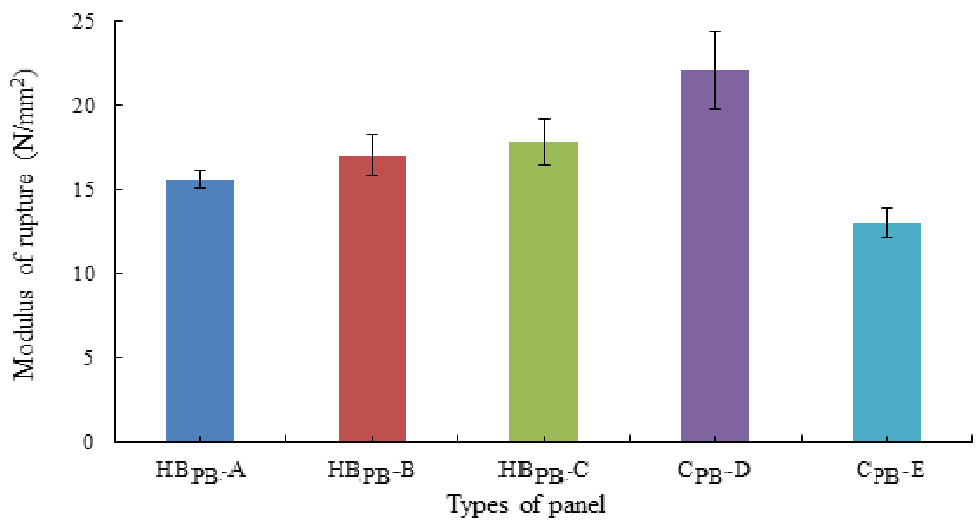

Fig. 6. Modulus of rupture of hybrid and control particleboards

MOR of HB_{PB}-C particleboards were found to be within the range of ANSI A208.1 requirements for medium density particleboard of M-3 grade.

4. CONCLUSION

From the results and discussion following conclusion can be drawn:

1. Particle ratios (wood or non-wood particle) have significant influences on the physical and mechanical properties of hybrid particleboard.
2. Hybrid particleboard (HB_{PB}-C: Kenaf: kadam-50:50) produced from a mixture of 60% coarse (kadam and kenaf in core) and 40% fine particles (kadam and kenaf in face back) showed higher physical and mechanical properties compared to HB_{PB}-A (kenaf: kadam-40:60), HB_{PB}-B (kadam: kenaf-40:60) and C_{PB}-E (kadam 100%) but lower than the control particleboard C_{PB}-D (kenaf 100%) produced from 100% kadam particles.
3. Depending on the percentage of particles (i.e., non-wood and wood particle ratio in the formulation) in the face, back and core of particleboard, physical and mechanical properties of hybrid particleboard varied.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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