Nitu *et al. J Wood Sci* (2020) 66:65
https://doi.org/10.1186/s10086-020-01913-z

Journal of Wood Science

ORIGINAL ARTICLE

Open Access

Optimization of processing parameters for the manufacturing of jute stick binderless particleboard

Ireen Parvin Nitu[1*], Md Nazrul Islam[1], Md Ashaduzzaman[1], Md Khairul Amin[2] and Md Iftekhar Shams[1]

Abstract

This study investigated the effects of processing parameters, namely particle mixing ratios, press temperatures, and time for the manufacturing of jute stick binderless particleboard (JBPB). Different ratios of fine and coarse particles, press temperature (160 to 240 °C) and press time (4 to 10 min) were used for JBPB fabrication with a target density of 0.9 g/cm^3. The dimensional stability and mechanical properties of JBPB were determined according to Japanese Industrial Standard JIS A 5908 (2003). The result shows that the most favorable pressing conditions in the manufacturing process were press temperature of 220 °C for 6 min with a mixing ratio of 50:50 (fine: coarse). The modulus of rupture (MOR), modulus of elasticity (MOE), and internal bonding (IB) of JBPB was 16.35 N/mm^2, 3872.99 N/mm^2, and 1.07 N/mm^2, respectively, which met the minimum requirement for type-18 of particleboard JIS A 5908 (2003) except for the value of MOR. The bonding mechanism was analyzed by the chemical changes in the raw materials after the fabrication of JBPBs. The pentosans present in the raw material decreased with the increased press temperatures. In this study, the hemicellulose was decomposed which may accelerate the self-bonding of the JBPB at high temperatures. The thermal gravimetric analysis (TGA) revealed that the JBPB showed good thermal stability with the increase of press temperatures. Fourier transform infrared (FTIR) spectra indicated that the removal of hydroxyl groups which increased the dimensional stability of JBPBs. Hence, it could be concluded that by controlling particle mixing ratio (50:50) at high press temperature with proper press time, high-performance jute stick binderless particleboard could be successfully developed which has a variety of applications.

Keywords: Jute stick, Particleboard, Self-bonding, Dimensional stability, Mechanical property, Chemical analysis

Introduction

In recent years, demand for particleboard/composite materials has been growing rapidly all over the world [1, 2] as well as in Bangladesh. Therefore, deforestation has occurred due to a complete dependency on forest resources for raw material supply with the increasing demand for infrastructural development [3]. On the other hand, formaldehyde is the main component of adhesives which has been widely used in the particleboard industry. Hence, formaldehyde-based adhesives are not considered as environmentally friendly for end-users because of health concerns [4]. Addressing such issues, it is high time to thinking about the alternative practice in the replacement of the conventional adhesive-based products for the end-users [5]. To eliminate these concerns, many researchers have been investigating the properties of binderless particleboard (BPB) made from agricultural residues such as kenaf core, oil palm, sugarcane bagasse, rice straw, almond, and coconut husks [6–11].

The concept of BPB has attracted keen interest of many researchers due to its environmentally friendly approach, as particleboards are biodegradable and less hazardous when compared to the traditional type of panel. BPBs appeared to be such products that can be manufactured without adding any synthetic adhesive, only activating

*Correspondence: ireenparvinnitu@gmail.com
[1] Forestry and Wood Technology Discipline, Khulna University, Khulna 9208, Bangladesh
Full list of author information is available at the end of the article

the chemical components of the board constituents during steam/heat treatment [12]. The hemicellulose of raw material supposed to be degraded during steam/heat treatment which produces some furan products that can take part in self-bonding for board preparation [13]. Okuda et al. [14] reported that the decomposition of hemicelluloses and lignin during hot pressing could accelerate the self-bonding of kenaf particleboard. Widyiorini et al. [15] have suggested that the breakage of hemicelluloses and cellulose produces simple sugar which contributes to self-bonding in kenaf core BPB. Generally, BPB can be bonded through the thermo-compression process [3]. The different chemical reaction might have occurred such as degradation of hemicelluloses and part of the lignin which produce simple sugars and other decomposition products [16]; thermal softening of the cell wall matrix [17]; and crosslinking between carbohydrate polymers and lignin [18].

Bangladesh is an agro-based country and produces a substantial quantity of agricultural residues every year, especially jute stick which is obtained after separating the fiber. The annual production of jute sticks in Bangladesh is around 3.0 million tons [19]. These huge amounts of jute stick remain unused or only use as fuel in the rural area rather has no industrial uses [20]. Meanwhile, the chemical composition of jute stick consists of cellulose (40.8%), hemicellulose (32.9%), lignin (23.5%), ash (0.8%), and other substances (1%) [21]. Hence, the availability of hemicellulose richness of jute stick implies that these can be the promising candidate for the development of BPBs [22]. Many researchers have worked on different pressing parameters namely press temperature, press time, particle geometry on the properties of BPBs [23–25]. However, to our knowledge, no one has paid attention to fabricate BPB using jute stick until today. Hence, the objective of this study was to examine the optimum processing parameters, namely particle mixing ratio, press temperature, and press time for the manufacturing of jute stick binderless particleboard (JBPB).

Materials and methods

Jute sticks (*Corchorus capsularis*) were collected from the local market of Khulna district, Bangladesh. The jute sticks were air-dried for 3 weeks. The sticks were then cut into small pieces, and the small pieces were converted into smaller particles using laboratory scale grinder, (Bangladesh). The particles were passed through 10 to 60 meshes to get fine and coarse particles. The average moisture content of the air-dried jute stick particle was 13% determined by moisture analyzer (Axis, ATS 120 Poland). Then the particles were stored in airtight packs until further use.

Manufacturing of binderless particleboards

Two types of JBPB namely layered (fine particle in two face layer and coarse particle in core layer) and mixed (a mixture of the coarse and fine particle) JBPB was attempted at first. The air-dried jute stick particles were hand-formed into a mat using a forming box. The mats were pressed at press temperatures of 180 °C for 10 min with 5 MPa pressures [26]. The prepared layered JBPB named as JBPB-L and mixed JBPB named as JBPB-M with different particle mixing ratio from 30 to 50 wt% (fine: coarse) were used in this study. Single-layer particleboard from 100% coarse named JBPB-0 and 100% fine named JBPB-100 was also made under the same condition as the above was applied. The mixing ratio of particles for the production of JBPB is presented in Table 1. To investigate the effect of press temperature on the properties of JBPB, temperature ranges from 160 to 240 °C for 10 min with 5 MPa pressure at an optimized mixing ratio was applied in the next. The JBPBs named JBPB-180, JBPB-200, and JBPB-220 for press temperatures of 180, 200, and 220 °C were manufactured. After that different press time (4 to 8 min) was applied at optimized press temperature and mixing ratio named JBPB-220 for 4 min, JBPB-220 for 6 min, and JBPB-220 for 8 min. The dimensions of JBPBs were $300 \times 200 \times 6$ mm. The target density of all the JBPB was around 0.9 g/cm^3 by controlling the thickness bar during pressing. Prior to testing, all of the JBPBs were conditioned for a week at 25 °C and 60% relative humidity (RH).

Evaluation of dimensional stability and mechanical properties of JBPB

The dimensional stability and mechanical properties of the JBPB were evaluated in accordance with the Japanese Industrial Standard for Particleboards (JIS A 5908, 2003) [27]. The static bending test was conducted at $300 \times 50 \times 6$ mm specimens from each JBPB using

Table 1 Mixing ratio of particles for the production of Jute Stick Binderless Particleboard (JBPB)

Board type	Mixing ratio (%)	Fine (%)	Coarse (%)
JBPB-0	0	0	100
JBPB-L30*	30	30	70
JBPB-L40*	40	40	60
JBPB-L50*	50	50	50
JBPB-M30**	30	30	70
JBPB-M40**	40	40	60
JBPB-M50**	50	50	50
JBPB-100	100	100	0

*Layered JBPB named as JBPB-L; **Mixed JBPB named as JBPB-M

a three-point bending test through universal testing machine (SHIMADZU AG-50KNXplus, Japan) over an effective span of 150 mm at a loading speed of 10 mm/min. Five 50 × 50 mm test specimens were prepared from each sample of JBPB for internal bonding (IB) tests. Five specimens of the same size from each sample of JBPB were prepared for water absorption (WA) and thickness swelling (TS) tests for 24 h water immersion.

Chemical analysis

Jute stick and the manufactured JBPBs were ground (40/60 mesh) using a wiley mill, (code 912, India). The preparation of extractive free samples was done according to TAPPI T 204 cm-97 [28]. The Klason lignin (TAPPI T 222 om-98) [29] and pentosans (TAPPI T 223 cm-84) [30] were determined in accordance with TAPPI Test Methods. Holocellulose content was determined by treating extractive free samples with the methods of wise et al. [31], while the α-cellulose content was measured by the extraction of the holocellulose with 17.5% NaOH. Hemicellulose content was calculated by subtracting the α-cellulose content from the holocellulose content. All of the chemical component analyses were performed in triplicate.

High-Performance Liquid Chromatography (HPLC) (Shimadzu Prominence-I) was used to determine the neutral sugar composition of the polysaccharide. 100 mg of samples were hydrolyzed in 72% (w/w) H_2SO_4. Then the mixture was autoclaved and filtered using a microfilter with the pore size of 0.45 µL and the sample was deionized to water v/v [Acetonitrile (ACN): Water = 80:20]. The samples were then placed into the HPLC auto sampler rack for analysis and the column Shim_pack GIST NH_2 5 µm with a mobile phase was used with a flow rate of 1 mL/min at 40 °C. The pH of the sample was 7–7.5. Pure glucose and xylose were used as standards.

Fourier transform infrared spectroscopy (FTIR)

Jute sticks and manufactured JBPBs were ground into a fine powder by a high-speed blender and dried in an oven at 60 °C for 12 h. Infrared spectrum data were obtained through FT-IR Spectrometer (Spectrum Two PerkinElmer, USA). Data was recorded between wavenumbers of 3500 cm^{-1} and 500 cm^{-1} using the Universal Attenuated Total Reflectance (UATR) method.

Thermal gravimetric analysis (TGA)

Jute sticks and manufactured JBPBs were crushed into fine powder by a high-speed blender and dried in an oven at 60 °C for 12 h. The TG was conducted using a LABSys Evo STA (Simultaneous Thermal Analysis, Setaram Instrumentation, France). Scans were recorded from room temperature to 500 °C using a carrier gas (N_2) at a heating rate of 5 °C/min.

Results and discussion

Dimensional stability

The layered (JBPB-L) and mixed (JBPB-M) JBPB showed higher WA and TS values among all the manufactured JBPBs. Due to the hydrophilic properties of lignocellulosic materials and the capillary action induced uptake of water when soaking into the water and thus increased the WA and TS values [32, 33]. The dimensional stabilities of JBPB-L were lower compared to the JBPB-M, as shown in Table 2. The proper combination of fine and coarse particles in the JBPB-M seems to be the better interlocking among the particles compared with the JBPB- L [9, 34]. Adding fine particles results in reduced void space and irregularities in JBPB-M which could help to reduce the penetration of water, whereas in JBPB-L, the surface

Table 2 Effects of particle mixing ratios on the dimensional stability and mechanical properties of Jute Stick Binderless Particleboard (JBPB). Press temperature was 180 °C for 10 min

Board type	Dimensional stability		Mechanical properties		
	WA (%)	TS (%)	MOR (N/mm^2)	MOE (N/mm^2)	IB (N/mm^2)
JBPB-0	107.78* (7.13)**	89.81* (5.73)**	8.69* (2.06)**	1436.43* (261.23)**	0.17* (0.05)**
JBPB-L30	123.39* (18.50)**	99.43* (4.08)**	11.29* (2.29)**	2926.83* (251.81)**	0.22* (0.07)**
JBPB-L40	109.99* (9.25)**	83.89* (6.32)**	10.94* (1.21)**	2627.82* (241.14)**	0.26* (0.50)**
JBPB-L50	88.14* (5.13)**	70.89* (11.08)**	8.85* (2.38)**	2072.88* (352.69)**	0.28* (0.14)**
JBPB-M30	81.36* (8.24)**	69.38* (17.03)**	12.31* (1.57)**	2630.58* (310.11)**	0.59* (0.18)**
JBPB-M40	68.69* (16.77)**	60.67* (11.24)**	12.34* (3.92)**	3259.08* (325.36)**	0.65* (0.20)**
JBPB-M50	62.57* (10.04)**	41.89* (3.77)**	14.23* (2.15)**	3318.86* (390.72)**	0.73* (0.13)**
JBPB-100	80.96* (15.55)**	69.27* (8.91)**	9.12* (2.37)**	2319.42* (383.12)**	0.25* (0.02)**

*Values presented are average of 10 samples; **Values presented in parenthesis are standard deviation; L for layered JBPB and M for mixed JBPB

consists of only fine particles and core part is fully composed of coarser particles. The WA and TS values of JBPB-M50 were 58.13% and 41.89%, while for JBPB-L50, it was 88.14% and 70.89%, respectively. The WA and TS values of JBPB decreased with increased press temperature from 180 to 220 °C, as shown in Fig. 1. For example, the WA value and the TS value of JBPB-220 was 46.26% and 38.53%, respectively, which is lower than the WA and TS values of JBPB-180 for 10 min. It seems that high temperature starts to degrade the hemicelluloses which reduce free reactive hydroxyl groups thus decreases the ability to bind water [26]. Furthermore, considerable differences in JBPBs were noticed as a function of press time at a press temperature of 220 °C, as shown in Fig. 2. The WA value and the TS value of JBPB-220 for 6 min was 42.78% and 20.69%, respectively, which was lower than that of other press times of JBPB-220. Better dimensional stability at a high press temperature of 215 °C and at a lower press time of 5 min was previously reported [35]. In this study, the interaction between two factors (mixing of fine particles and high press temperature) at lower press time noticeably affected the WA and TS.

Mechanical properties

Table 2 shows the properties of JBPB-L and JBPB-M with different particle mixing ratio at the press temperature of 180 °C for 10 min. The results showed that the JBPB-M had higher modulus of rupture (MOR), modulus of elasticity (MOE), and IB values compared to the JBPB-L. Interestingly, the mechanical properties of the JBPB-M increased when fine particle content increased from 30 to 50% and above the 50% fine particle content of JBPB had poor performance in mechanical properties. Additionally, JBPB-0 had lower MOR, MOE, and IB values than those of JBPB-100. For example, JBPB-M50 had the highest modulus of rupture values of 14.23 N/mm^2 and modulus of elasticity values of 3318.86 N/mm^{2,} while JBPB-L50 had 8.85 N/mm^2 and 2072.88 N/mm^2, respectively. In JBPB-L, the surface consists of fine particles and core part is fully composed of coarser particles, on the contrary, the proper interlocking of fine and coarse particles in the JBPB-M might be effective for increasing the mechanical properties of the JBPB. It seems that fine particles work as fillers in coarse particles for JBPB-M [36]. Lui et al. [37] reported that adding fine particles contributes to the improvement of the bonding strength of the board. Since, fine particles provide a larger contact area among particles compared to coarse particles, resulting in stronger bonding of JBPB-100 compared to JBPB-0 [26]. Particle geometry including different shape and size of particles may have a potential influence on the mechanical properties of the boards [38]. Sackey et al. [39] pointed out that the fine particle content and the ratio of particle size fractions strongly influenced the internal bond strength of the boards. However, fine particles require higher energy to manufacture and were difficult to handle with a higher percentage in the JBPB fabrication process [26]. Thus, the mixing ratio at 50:50

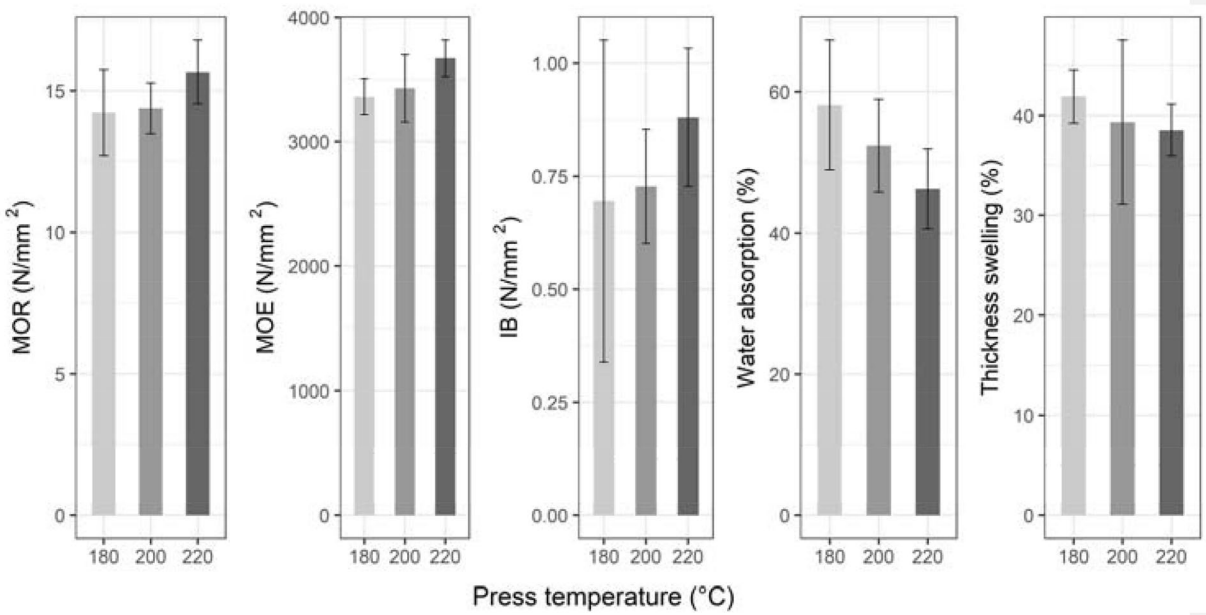

Fig. 1 Dimensional stability and mechanical properties of jute stick binderless particleboard (JBPB) as a function of press temperatures. Error bar indicates the standard deviation

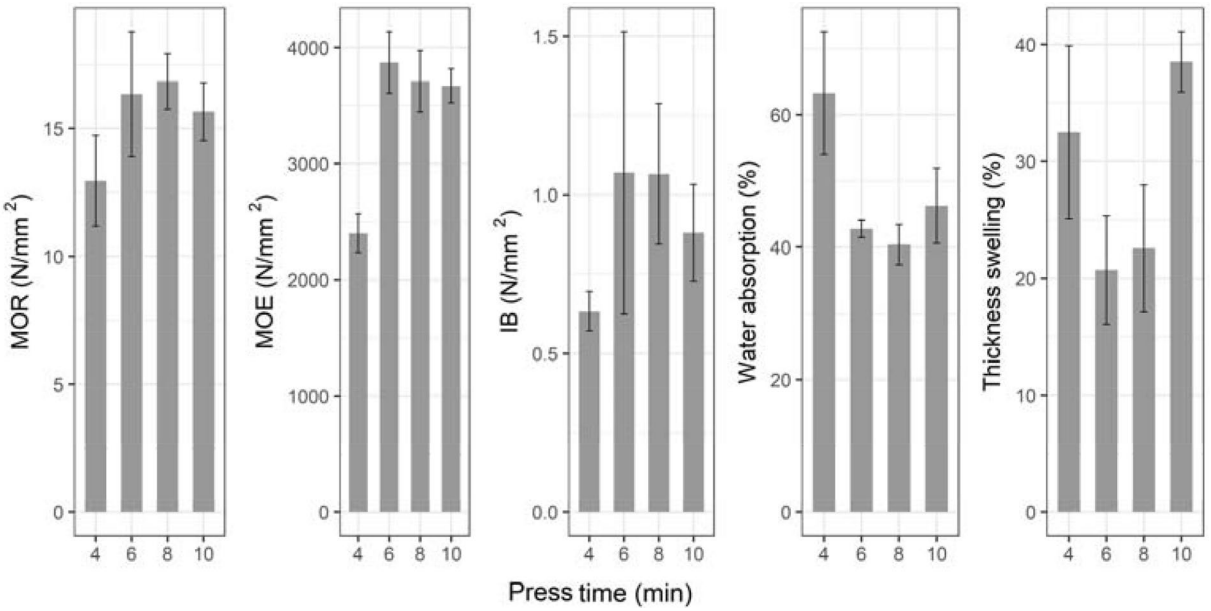

Fig. 2 Dimensional stability and mechanical properties of jute stick binderless particleboard (JBPB) pressed at 220 °C as a function of press times. Error bar indicates the standard deviation

(fine: coarse) was better compared to the other mixing composition in this study.

Figure 1 shows the influence of press temperature on the properties of JBPBs at an optimized mixing ratio of 50:50 (fine: coarse). When JBPBs were hot-pressed at 160 °C, spring back occurred due to the poor bonding, which felt below the target density indicating that bonding was not sufficient at this temperature. On the other hand, when JBPBs were hot-pressed at 240 °C, it tends to burn due to the gasification of the raw materials; hence, it could not evaluate the properties of JBPBs. The JBPB was lighter in color at 180 °C press temperature while increasing the temperature from 180 to 220 °C; the color tends to be darker due to the effect of degradation of chemical components. The MOR values of JBPB increased with increasing press temperatures from 180 to 220 °C for 10 min. The JBPB-220 had the highest MOR values of 15.67 N/mm^2 which was 10.12% higher compared to the JBPB-180. Similarly, the MOE values improved with the increase of press temperatures. Internal bond strength was also increased when press temperature increased from 180 to 220 °C. For example, the IB values of JBPB-220 were 0.88 N/mm^2 which was 27.54% higher than that of JBPB-180 for 10 min. This indicated that a press temperature of 220 °C is the effective temperature in terms of bending properties. Due to the high press temperature, the degradation of chemical components of jute stick may occur which might play an important role in better bending strength [8, 22]. Since the hemicelluloses of lignocellulose material, including jute stick, decomposes at 220–315 °C, the JBPB-180 might have not reached an effective temperature during hot pressing [40]. Hence, it can be said that press temperature of 220 °C was optimum temperature for obtaining good mechanical properties in JBPB fabrication.

The effects of press time on mechanical properties of JBPB were investigated under a press temperature of 220 °C. Figure 2 shows the mechanical properties of JBPB at different press times. The MOR, MOE, and IB values of JBPB-220 were increased from 4 to 6 min and then decreased slightly at 8 min. The IB value of the JBPB-220 for 4 min showed extremely low value. The internal bonding strength was reported to 1.07 N/mm^2 for JBPB-220 for 6 min, which was 21.5% higher compared to JBPB-220 for 10 min. The target temperature reached in the core layer of particleboard was slower than in the surface layers during hot-pressing. At 4 min press time, the target temperature in the core layer may not be reached resulting in poor adhesiveness in the core layer. On the other hand, at 10 min press time, the target temperature in the core layer may be reached, while the surface layer may be degraded due to long press time results in reduced mechanical properties. Press time 6 min might be effective to achieve the target temperature of the core layer and did not degrade the surface layer. Press temperature of 220 °C for 6 min was needed to obtain good adhesiveness in all layers for the JBPB production and showed higher mechanical properties. Hence, to understand

Table 3 Chemical compositions of Jute stick and Jute Stick Binderless Particleboard (JBPB) pressed at different press temperatures and times

Chemical components (%)	JS-Raw	JBPB-180 10 min	JBPB-200 10 min	JBPB-220 10 min	JBPB-220 8 min	JBPB-220 6 min
Lignin	22.0* (0.74)**	23.0* (0.58)**	21.0* (0.38)**	23.0* (0.74)**	25.3* (0.63)**	24.6* (0.31)**
Pentosan	19.7* (0.58)**	17.2* (0.16)**	15.3* (0.44)**	14.3* (0.23)**	12.9* (0.36)**	12.7* (0.26)**
Holocellulose	63.0* (0.28)**	63.0* (0.61)**	61.0* (0.46)**	60.0* (0.28)**	59.6* (0.49)**	59.5* (0.48)**
α-cellulose	34.0* (0.10)**	35.0* (0.21)**	35.0* (0.43)**	35.0* (0.62)**	35.4* (0.55)**	35.9* (0.28)**
Hemicellulose	29.0* (0.17)**	28.0* (0.21)**	26.0* (0.26)**	25.0* (0.52)**	24.2* (0.31)**	23.5* (0.50)**

*Values presented are average of 3 samples; **Values presented in parenthesis are standard deviation

Table 4 Sugar contents of Jute stick and Jute Stick Binderless Particleboard (JBPB) pressed at different press temperatures and times

Sugar compounds (%)	JS-Raw	JBPB-180 10 min	JBPB-200 10 min	JBPB-220 10 min	JBPB-220 8 min	JBPB-220 6 min
Glucose	29.9* (0.12)**	28.9* (0.40)**	29.2* (0.28)**	31.1* (0.53)**	33.58* (0.52)**	37.14* (0.24)**
Xylose	14.5* (0.43)**	9.8* (0.25)**	9.4* (0.18)**	9.1* (0.18)**	8.83* (0.19)**	8.37* (0.27)**

*Values presented are average of 3 samples; **Values presented in parenthesis are standard deviation

clearly, the chemical changes of manufactured JBPBs during hot pressing were investigated.

Table 3 shows the chemical composition of the jute stick and manufactured JBPBs as a function of press temperatures. The holocellulose content of jute stick decreased in manufactured JBPBs, as depicted in Table 3. It can be explained due to the degradation of the hemicelluloses during hot pressing. In addition, the pentosan content in the original jute stick was 19.7% decreased to 17.3% after fabricating JBPB-180 for 10 min, which was further decreased to 12.63% for JBPB-220 for 6 min. This result indicates that pentosans present in the raw material might be converted into furfural at a higher temperature, which may improve the IB values of the JBPB [26]. These results were consistent with the sugar content data of jute stick and manufactured JBPBs, as shown in Table 4. It was found that glucose and xylose were predominant sugar constituents in all the samples. Xylose decreased constantly with increasing press temperature which was consistent with the decomposition of hemicellulose. For example, JBPB-220 for 6 min had the lowest xylose content (8.37%) compared to the other JBPBs. On the other hand, higher content of glucose was found at higher temperatures due to the sum of glucose derived from the cellulose [41]. For example, JBPB-220 for 6 min had the highest glucose content of 37.14% showed an increment in the glucose content compared to the other JBPBs. The above analysis can explain that the decomposition of hemicellulose produced decomposed components resulting in the formation of adhesives during hot pressing that binds the particle together. In contrast, α-cellulose content has no obvious differences among jute stick and the manufactured JBPBs, as presented in Table 3. The lignin content cannot ensure its participation in making bonding through resinification in this study. Hence, further study is underway and will be reported in details in another article.

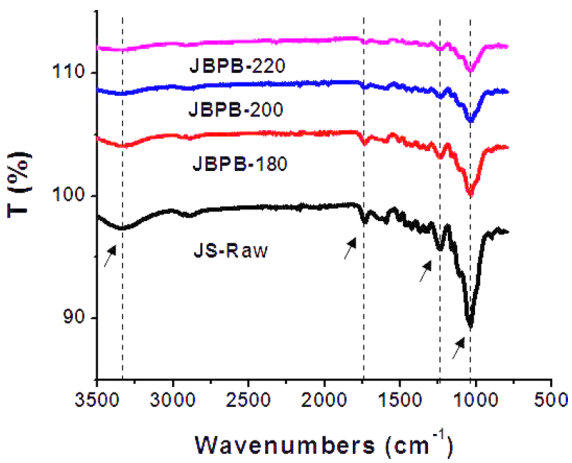

Fig. 3 Fourier transform infrared spectra of jute stick particles and manufactured jute stick binderless particleboard (JBPB) as a function of press temperatures

Changes of chemical structure

Changes in the chemical structure of the boards manufactured at different press temperatures were measured by FTIR and the results are shown in Fig. 3. The

peak at 3400 cm^{-1} is attributed to the H-bonded O–H stretching within the constituents and the peak intensity decrease with the increase of press temperatures. It reveals the weakening of H-bonding and loss of hydrous components [42]. In the C=O stretching region, the peak at 1750 cm^{-1} is associated with absorbed water, since hemicelluloses have strong hydrophilic nature [43]. The lowering of the peak intensity with increasing press temperature is directly linked with the removal of water contents from the manufactured JBPBs, which yields excellent stability. The peak at 1250 cm^{-1} derived from aryl ether structure [44] decreased with pressing temperature which indicates the inter-monomer linkages in lignin during pressing [8]. The peaks at 1034 cm^{-1} were mainly derived from hydroxyl groups in polysaccharides [16] and the decreased intensity from 180 to 220 °C implied that the polysaccharides may lead to the enhancement of bonding properties.

Thermal stability of the JBPB

Figure 4 shows the thermo gravimetric (TG) curve of manufactured JBPBs at different press temperatures. The curve shows that the minimal weight loss below 120 °C which is attributed to the removal of hydroxyl groups of the materials [45]. After that, significant mass losses started when the temperature increased between 200 °C and 300 °C which indicated the thermal degradation of hemicelluloses [46]. The weight loss occurred between 300 and 400 °C, is associated with the degradation of α-cellulose [47]. The JBPB-180 and JBPB-200 showed a higher weight loss of 22.91% and 29.41%, respectively, while JBPB-220 had the highest initial degradation temperature and the lowest weight loss of 14.48%. This indicates that JBPB-220 has good thermal stability. These results revealed that JBPB-180 and JBPB-200 were thermally degraded faster compared to JBPB-220. The reason can be explained by the formation of hydrogen bonds due to hot pressing and with increasing of press temperature up to 220 °C auto-crosslinking polymer chains started [48] thus tough to be broken in JBPB-220 board which increases its stability.

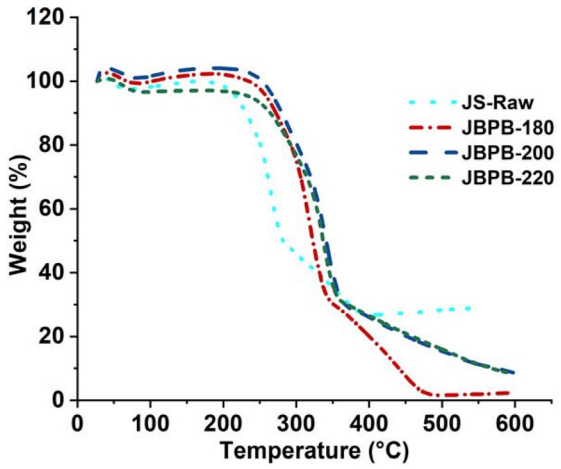

Fig. 4 Thermogravimetric (TG) curve of jute stick particles and manufactured jute stick binderless particleboard (JBPB) as a function of press temperatures

Conclusions

Jute stick binderless particleboard was successfully manufactured by optimizing the processing parameters namely mixing ratio of fine and coarse particles, press temperatures, and time in this study. The most favorable pressing conditions in the manufacturing process were observed at a press temperature of 220 °C for 6 min with a mixing ratio of 50:50 (fine: coarse). At optimum pressing conditions, the MOR, MOE, and IB of JBPB were 16.35 N/mm^2, 3872.99 N/mm^2, and 1.07 N/mm^2, respectively. Chemical analysis confirmed the degradation of hemicellulose with increasing press temperature. Pentosans might be converted into furfural with increasing press temperature which was consistent with sugar content, as xylose decreased constantly with increasing press temperature ensuring the self-bonding of JBPB. Since adhesive is not added when manufacturing these JBPBs, and the products are free from formaldehyde emission, making them especially suitable for a variety of interior applications.

Abbreviations

BPB: Binderless particleboard; JBPB: Jute stick binderless particleboard; SD: Standard deviation; WA: Water absorption; TS: Thickness swelling; MOR: Modulus of rupture; MOE: Modulus of elasticity; IB: Internal bonding; HPLC: High performance liquid chromatography sugar analysis; FTIR: Fourier transform infrared spectra; TGA: Thermal gravimetric analysis.

Acknowledgements

The first author would like to acknowledge the Higher Education Quality Enhancement Project (HEQEP) CP 4035 funded by World Bank and Ministry of Education, the People's Republic of Bangladesh for the fellowship support. The authors like to thank Bangladesh Council of Scientific and Industrial Research (BCSIR) for chemical analysis of the samples. The authors are grateful to Professor Dr. Md Nabiul Islam Khan, Forestry and Wood Technology Discipline, Khulna University, Bangladesh for his contribution to graphical presentation.

Authors' contributions

MIS performed the research plan and IPN collected the data for evaluating the properties of jute stick binderless particleboard. MA performed the literature search. IPN, MIS and MKA performed the data analysis. IPN prepared the first draft of the manuscript. IPN, MIS and MNI were the major contributors for finalizing the manuscript. All authors read and approved the final manuscript.

Funding

Higher Education Quality Enhancement Project (HEQEP) CP 4035 funded by World Bank and Ministry of Education, People's Republic of Bangladesh.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests
The authors declare that they have no competing interests.

Author details
[1] Forestry and Wood Technology Discipline, Khulna University, Khulna 9208, Bangladesh. [2] Chemistry Discipline, Khulna University, Khulna 9208, Bangladesh.

Received: 10 April 2020 Accepted: 11 September 2020
Published online: 22 September 2020

References

1. Sellers T (2000) Growing markets for engineered products spurs research. Wood Technol 127(3):40–43
2. Pan Z, Cathcart A, Wang D (2006) Properties of particleboard bond with rice bran and polymeric methylene diphenyl diisocyanate adhesives. Ind Crops Prod 23(1):40–45
3. Zhang D, Zhang A, Xue L (2015) A review of preparation of binderless fiberboards and its self-bonding mechanism. Wood Sci Technol 49(4):661–679
4. Nath DC, Mwchahary DD (2012) Population increase and deforestation: a study in Kokrajhar district of Assam. Int J Sci Res Publ 2(10):1–12
5. Nitu IP, Shams MI, Islam MN, Ratul SB, Ashaduzzaman M (2018) Development of binderless composites from different nonwood lignocellulosic materials: overview. In: Martínez L, Kharissova O, Kharisov B (eds) Handbook of ecomaterials. Springer, Cham, pp 1–15
6. Xia Z, Xu JY (2010) Effect of different hot-pressing technology on mechanical properties of binderless particleboard from kenaf core. In 2010 International Conference on Mechanic Automation and Control Engineering, IEEE, pp 5366–5368
7. Lee SH, Ashaari Z, Ang AF, Halip JA, Lum WC, Dahali R, Halis R (2018) Effects of two-step post heat-treatment in palm oil on the properties of oil palm trunk particleboard. Ind Crops Prod 116:249–258
8. Nonaka S, Umemura K, Kawai S (2013) Characterization of bagasse binderless particleboard manufactured in high-temperature range. J Wood Sci 59(1):50–56
9. Kurokochi Y, Sato M (2015) Properties of binderless board made from rice straw: the morphological effect of particles. Ind Crops Prod 69:55–59
10. Ferrandez-Villena M, Ferrandez-Garcia CE, Garcia Ortuño T, Ferrandez-Garcia A, Ferrandez-Garcia MT (2019) Study of the utilisation of almond residues for low-cost panels. Agronomy 9(12):811
11. Junior CPA, Coaquira CAC, Mattos ALA, de Souza MDSM, de Andrade Feitosa JP, de Morais JPS, de Freitas Rosa M (2018) Binderless fiberboards made from unripe coconut husks. Waste Biomass Valoriz 9(11):2245–2254
12. Rowell R, Lange S, McSweeny J, Davis M (2002) Modification of wood fiber using steam. In: Proceedings of the 6th Pacific Rim Bio-Based Composites Symposium & Workshop on the Chemical Modification of Cellulosics, Portland, Oregon, USA, October 27th, 2002, Volume 2. Wood Science and Engineering Dept. Oregon State University, Corvallis, Oregon, USA, pp 606–615
13. Shen KC (1986) Process for manufacturing composite products from lignocellulosic materials. U.S. Patent no. 4,627,951
14. Okuda N, Hori K, Sato M (2006) Chemical changes of kenaf core self-bonded boards during hot pressing (I): influence of the pressing temperature condition. J Wood Sci 52(3):244
15. Widyorini R, Xu J, Watanabe T, Kawai S (2005) Chemical changes in steam-pressed kenaf core self-bonded particleboard. J Wood Sci 51(1):26–32
16. Fahmy TY, Mobarak F (2013) Advanced binderless board-like green nanocomposites from undebarked cotton stalks and mechanism of self-bonding. Cellulose 20(3):1453–1457
17. Inoue M, Norimoto M, Tanahashi M, Rowell RM (2007) Steam or heat fixation of compressed wood. Wood Fiber Sci 25(3):224–235
18. Suzuki S, Shintani H, Park SY, Saito K, Laemsak N, Okuma M, Iiyama K (1998) Preparation of self-bonded boards from steam exploded pulps of oil palm (*Elaeis guneensis* Jaxq.) fronds and structural characteristics of lignin and wall polysaccharides in steam exploded pulps to be discussed for self-bindings. Holzforschung 52(4):417–426
19. Matin M, Rahaman MM, Nayeem J, Sarkar M, Jahan MS (2015) Dissolving pulp from jute stick. Carbohyd Polym 115:44–48
20. Karim MS, Seal HP, Rouf MA, Rahman MI, Talukder MHR, Karmaker PG (2010) Acetic acid pulp from jute stick, rice-straw and bagasse. J Agrofor Environ 3(2):171–174
21. Rahman MM, Siddiqua S, Akter F, Jahan MS, Quaiyyum MA (2016) Variation of morphological and chemical properties of three varieties of jute stick. Bangladesh J Sci Ind Res 51(4):307–312
22. Nayak L, Roy A (2011) Utilization of jute by-products: a review. Agric Rev 32(1):63–69
23. Hashim R, Said N, Lamaming J, Baskaran M, Sulaiman O, Sato M, Hiziroglu S, Sugimoto T (2011) Influence of press temperature on the properties of binderless particleboard made from oil palm trunk. Mater Des 32:2520–2525
24. Baskaran M, Hashim R, Sulaiman O, Hiziroglu S, Sato M, Sugimoto T (2015) Optimization of press temperature and time for binderless particleboard manufactured from oil palm trunk biomass at different thickness levels. Mater Today Commun. 3:87–95
25. Hashim R, Saari N, Sulaiman O, Sugimoto T, Hiziroglu S, Sato M, Tanaka, R (2010) Effect of particle geometry on the properties of binderless particleboard manufactured from oil palm trunk. Mater Des 31(9):4251–4257
26. Okuda N, Sato M (2004) Manufacture & mechanical properties of self-bonded boards from kenaf core. J Wood Sci 50(1):53–61
27. Japanese Standard Association (2003) Japanese Industrial Standard for particle board JIS A 5908. Japanese Standard Association, Tokyo
28. TAPPI T 204 cm-97 (1997) Solvent extractives of wood and pulp
29. TAPPI T 222 om-98 (1998) Acid-Insoluble lignin in wood and pulp
30. TAPPI T 223 cm-84 (1984) Pentosans in wood and pulp
31. Wise IE, Murphy M, D'Addieco AA (1946) Chlorite holocellulose, its fractionation and bearing on summative wood analysis and studies on the hemicelluloses. Pap Trade J. 122:35–43
32. Norul I, Paridah MT, Astimar AA, Mohd N, Anwar UMK (2012) Mechanical and dimensional stability properties of medium-density fibreboard produced from treated oil palm empty fruit bunch. J Appl Sci 12(6):561–567
33. Sulaiman O, Salim N, Hashim R, Yusof LHM, Razak W, Hasim WS, Azmy MH, Yunus NYM (2009) Evaluation on the suitability of some adhesives for laminated veneer lumber from oil palm trunks. Mater Des 30:3572–3580
34. Frybort S, Mauritz R, Teischinger A, Müller U (2008) Cement bonded composites–A mechanical review. BioResources 3(2):602–626
35. Anglès MN, Reguant J, Montané D, Ferrando F, Farriol X, Salvadó J (1999) Binderless composites from pretreated residual softwood. J of Appl Polym Sci 73(12):2485–2491
36. Ahmad Z, Tajuddin M, Halim MAMZ (2019) Effects of particle sizes on the properties of binderless boards made from Rattan Furniture Waste. J Eng 15:49–61
37. Lui FHY, Kurokochi Y, Narita H, Saito Y, Sato M (2018) The effects of chemical components and particle size on the mechanical properties of binderless boards made from oak (*Quercus* spp.) logs degraded by shiitake fungi (*Lentinula edodes*. J wood sci 64(3):246–255
38. Suchsland O, Woodson GE (1987) Fiberboard manufacturing practices in United States. USDA, Washington, p 263
39. Sackey EK, Semple KE, Oh SW, Smith GD (2008) Improving core bond strength of particleboard through particle size redistribution. Wood Fiber Sci 40(2):214–224
40. Yang H, Yan R, Chen H, Lee DH, Zheng C (2007) Characteristics of hemicellulose, cellulose and lignin pyrolysis. Fuel 86(12–13):1781–1788
41. Xiao B, Sun X, Sun R (2001) Chemical, structural, and thermal characterizations of alkali-soluble lignins and hemicelluloses, and cellulose from maize stems, rye straw, and rice straw. Polym Degrad Stab 74(2):307–319
42. Grzechnik A, McMillan PF (1998) Temperature dependence of the OH^- absorption in SiO_2 glass and melt to 1975 K. Am Miner 83(3–4):331–338
43. Sun RC, Fang JM, Tomkinson J, Geng ZC, Liu JC (2001) Fractional isolation, physico-chemical characterization and homogeneous esterification of hemicelluloses from fast-growing poplar wood. Carbohy Polym 44(1):29–39
44. Colom X, Carrillo F (2005) Comparative study of wood samples of the northern area of Catalonia by FTIR. J Wood Chem Technol 25:1–11
45. Peng F, Bian J, Peng P, Guan Y, Xu F, Sun RC (2012) Fractional separation and structural features of hemicelluloses from sweet sorghum leaves. BioResources 7(4):4744–4759
46. De Rosa IM, Kenny JM, Puglia D, Santulli C, Sarasini F (2010) Morphological, thermal and mechanical characterization of okra (*Abelmoschus*

esculentus) fibres as potential reinforcement in polymer composites. Compos Sci Technol 70(1):116–122
47. Kabir MM, Islam MM, Wang H (2013) Mechanical and thermal properties of jute fibre reinforced composites. J Multifunct Compos 1(1):71–77
48. Back EL (1987) The bonding mechanism in hardboard manufacture review report. Holzforschung-Int J Biol Chem Phys Technol Wood 41(4):247–258

Publisher's Note