

Characteristic of Bamboo Particleboard Bonded with Citric Acid

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Abstract

Converting biomass waste to high value-added product, such as biocomposite, tends to attract the interest of researcher and industry. Reducing the utilization of synthetic resin adhesives becomes one of the important points, considering the safe global environment. Binderlessboard is a product whose bonding depends mainly on the chemical composition of the raw materials. The aim of this research was to develop bio-based composites made from bamboo biomass waste materials. This report focused on the physical and mechanical properties of the particleboards. To improve the properties of the boards, the possibility of using citric acid was investigated and discussed. Petung bamboo particles (*Dendrocalamus asper* Backer) were used in this research. The contents of citric acid were ranged in 0% (binderlessboard), 10%, and 20% based on dried particles. The dimension of the boards was 25 x 25 x 0.7 cm, with the target density was 0.9 g/cm³. The particleboards were hot pressed at 200°C and 220°C for 10 and 15 min. The physical and mechanical properties of those particleboards were then evaluated based on Japanese Industrial Standard A 5908 for particleboard. The results showed that the physical and mechanical properties of the boards improved significantly by adding the citric acid. The bamboo particleboards obtained had good properties, with the specific IB, specific MOR and specific MOE values under the optimum condition of 20 wt % citric acid content and 200°C hot press were 0.44 MPa, 15.1 MPa and 4.6 GPa, respectively. It stated that bamboo particleboards bonded using citric acid had high performance on mechanical properties and good dimensional stability.

Keywords: petung bamboo, citric acid, binderlessboard, natural adhesive, pressing condition.

Introduction

Bamboo is a fast growing species and high potential renewable resources, therefore development of effective utilization of bamboo becomes more and more interesting. In Indonesia, Petung bamboo (*Dendrocalamus asper*) is one of the bamboo species that are abundantly available, which is widely used for housing. Production of bamboo particleboard as a waste byproduct from bamboo processing industry, is one of the value-added products supporting the zero-emission concept. More than 50% of the total chemical constituents in petung bamboo is holocellulose (Dransfield and Widjaja 1995). In previous research, bamboo binderless particleboard could be manufactured by using the hot pressing system without any delamination (Widyorini *et al.* 2011). This research showed that the binderless boards made from 20±2% moisture content particles can meet the Japanese Industrial Standard for particleboard and showed better mechanical as well as dimensional properties than those made from air-dried particles. However, the properties of the binderlessboard still need to be improved.

Without resin in producing binderlessboards, the performance of the boards is strongly affected by chemical characteristics of the raw materials. Therefore, activated chemical components during treatment or pressing are an effective process to build self-bonding in producing binderless board. Widyorini *et al.* (2005a) stated that partial degradation of the three major chemical components of the kenaf core by steam-injection pressing increased the bonding performance and dimensional stability of the binderless boards. However, the properties of those

binderless-boards still need to be improved, especially on the dimensional stability. Further development to improve the properties of the boards, with a safe and environmentally friendly technique, is very important. The possibility of using citric acid as a natural adhesive for wood was investigated by fabricating acacia wood and bark moldings (Umemura *et al.* 2011, 2012). Citric acid is a natural organic polycarboxylic acid, containing three carboxyl groups. The result showed that addition of citric acid improved the mechanical properties and water resistance of the wood and bark molding. Umemura *et al.* 2012 showed that the ester linkage has been detected by Fourier Transform Infrared Spectroscopy, indicating that the citric acid reacted with the wood and produced the good adhesion. The research of using citric acid as natural adhesive in composite production is still limited until now, especially on non-wood materials. There are no reports on bamboo particleboard bonded using citric acid, therefore this study focused on the effect of citric acid addition on the physical and mechanical properties of bamboo particleboards, while the other properties will be exposed on further report. The effect of citric acid content, pressing temperature, and pressing time on board properties were analyzed and discussed in this research. Binderlessboard from bamboo particles were also produced with the same hot pressing system condition.

Materials and Methods

Petung bamboo particles from Indonesia and citric acid were used as materials. The particles were passed through 10 mesh screen and were then air-dried to a moisture content

of around 12%. The citric acid was in solution (60 wt %) and the content (wt %) in mat were adjusted to 10% and 20% based on air-dried weight of particles. After particles and citric acid solution were mixed, they were dried in oven over night at 60°C. The particles and citric acid were then hand-formed into a mat by using forming box, followed by hot pressing into particleboard. The particleboards were then hot-pressed at 200°C and 220°C, with pressing time of 10 and 15 min. The dimensions of the particleboards were 250 x 250 x 7 mm, with the target board density was set at 0.9 g/cm³. Binderless particleboards from bamboo were also produced in the same condition. Three boards were manufactured in each condition. Prior to the evaluation of the mechanical and physical properties, the boards were conditioned at ambient conditions for about 10 days, reaching a moisture content of 5% ~ 7%.

The properties of the binderless particleboards were then evaluated basically according to the Japanese Industrial Standard for Particleboards (JIS A 5908 2003). Test were carried out for modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB) strength, and thickness swelling (TS) as well as water absorption (WA) after water immersion for 24 h. The specimens of 200 x 50 x 7 mm were prepared for each board for their static bending test. The three-point bending test was conducted over an effective span of 150 mm at a loading speed of 10 mm/min. One test specimens of 50 x 50 x 7 mm were prepared for each board for IB tests, and two specimens of the same size of each board were prepared for thickness swelling (TS) and water absorption (WA) tests after 24 h water immersion at 20°C.

Results and Discussion

All of particleboards in this study could be manufactured without any delamination, with the moisture content of binderless-boards ranged from 5% ~ 6% for all condition process. The boards density ranged from 0.73 to 0.79 g/cm³, and the density increased with increasing citric acid content, which ranged from 0.83 to 0.93 g/cm³. The boards hot-pressed at 220°C were darker in color and more brittle than boards hot-pressed at 200°C. It might be due to some chemical structures that were destroyed by the high pressing temperature. The darker color was also found at boards made from particles with citric acid, as also appeared in the acacia bark and wood molding (Umemura *et al.* 2011, 2012).

Physical Properties

Figure 1 shows relationship between TS and citric acid content of bambo particleboards. All of the TS value of the particleboards meet the requirement of JIS A 5908 (max 12 %), except for binderless particleboards that were hot pressed at 200°C. It clearly showed that increasing pressing temperature could reduce the TS of binderless particleboard. The average of TS value of binderlessboard that were

pressed at 200°C for 10 min was 21% and decreased to 5% when the binderlessboards were pressed at 220°C for 15 min. This study produced binderless-boards with relatively good result in dimensional stability, considering that all of the binderless-boards were made by hot pressing system. It might be due to the high temperature ($\geq 200^{\circ}\text{C}$) that was applied in this experiment, as mentioned by Okuda and Sato (2004). Sekino *et al.* (1999) indicated that the reduction in hygroscopicity, due to the changes in hemicelluloses during treatment, is one factor for the improved dimensional stability.

The TS of the particleboards improved significantly by adding the citric acid, as shown in Figure 1. The TS values of particleboards made at 200°C (binderlessboards) were 21% and 13%, for pressing time 10 min and 15 min, respectively. By adding 10% of citric acid, the TS of the boards were decreased to 5% and 6%, respectively. The same trend was also found by Umemura *et al.* (2011, 2012) that the molding bonded with citric acid had high water resistance. The wood-only molding decomposed completely during the first boiling treatment, while the form of the molding containing citric acid was maintained, irrespective of the amount of citric acid added during treatment (Umemura *et al.* 2012). Another research by Vukusic *et al.* (2006) has also found that the reduction in water absorption was also greater for citric acid treatment of fir and beech wood species, particularly when a higher concentration of citric acid was applied. Cross-linking chemicals reacting with hydroxyl groups reduce the hygroscopicity of wood and the tendency to swell or shrink (Rowell *et al.* 1988 in Vukusic *et al.* 2006).

Table 1 shows WA of bamboo particleboards at various conditions. The WA values of binderlessboard were affected significantly by pressing temperature. The average WA of binderlessboard was around 69% (200°C) and 32% (220°C) and decreased to 43% (200°C) and 34% (220°C), respectively. The same trend with TS, it showed that with the addition of citric acid, the WA of particleboards were significantly decreased. It seemed that bamboo particleboard using citric acid had high water resistance, as mentioned by Umemura *et al.* (2012) that addition of citric acid could improve the water resistance.

Internal Bond Strength

Figure 2 shows relationship between IB strength and citric acid content of bambo particleboards. The average IB values of binderless particleboards were 0.072 MPa and 0.097 MPa, at pressing temperature of 200 and 220°C for 10 min, respectively. The result was relatively low in IB strength compared to the previous report (Widyorini *et al.* 2011) in which the average IB strength of binderless board made from air-dried bamboo particles was 0.15 MPa. It might due to the difference of particle size and the composition of the particle used.

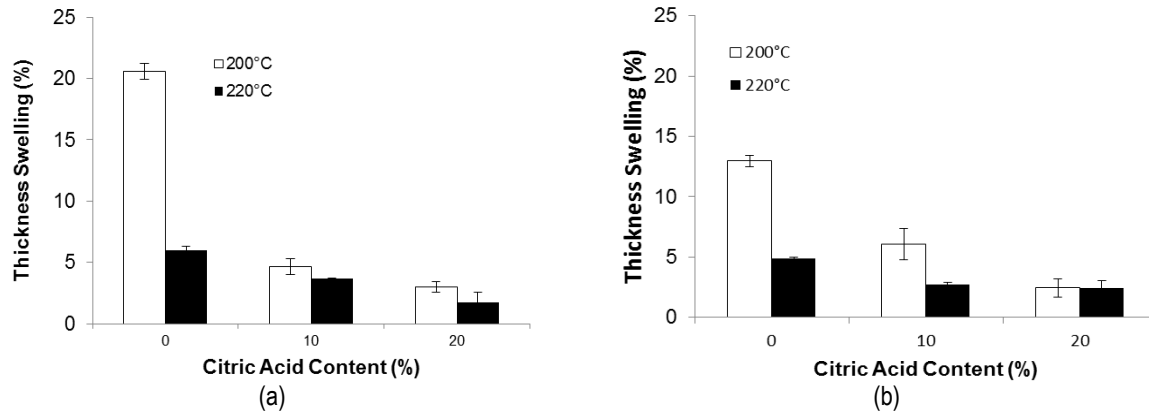


Figure 1. Relationship between thickness swelling and citric acid content of particleboards made from bamboo with pressing time (a) 10 min and (b) 15 min. Vertical lines through the bars represent the standard deviation from the mean.

Table 1. Water absorption of bamboo particleboards at various conditions.

No	Pressing temperature (°C)	Water Absorption (%)					
		0%		10%		20%	
		10 min	15 min	10 min	15 min	10 min	15 min
1	200	69	43	26	29	24	24
2	220	32	34	27	33	23	19

The properties of the binderlessboards were still relatively low and need to be improved. The IB value improved significantly as citric acid content increased. All of the boards made from particles and citric acid had IB strength that exceeded the minimum requirements for grade 8 type of JIS A 5908 for particleboards, i.e. 0.15 MPa. The maximum value was 0.36 MPa with 20 wt % of citric acid content at pressing temperature of 200°C for 10 min and the specific IB considering the density was 0.44 MPa. It meant that the particleboard had high performance on IB strength which can meet grade 18 type of JIS A 5908.

The IB values of bamboo particleboards were relatively high, especially when the boards were pressed at 200°C for 10 min. However, the result showed that the IB values decreased with increasing pressing time and pressing temperature. It suggested that intensive degradation had already occurred at high temperature and longer pressing time, resulting low performance of boards. Suzuki *et al.* (1998) reported that steam-exploded oil palm frond fiber at high steam pressure of 3MPa showed signs of great damage to lignin macromolecules and poor-quality binderless boards were manufactured. The mechanism of the bonding with citric acid is very important to be clearly understood, therefore the chemical compositions of the particles and chemical changes due to the processing will be a topic that will be discussed on further study.

Bending Strength

Figure 3 shows relationship between MOR and citric acid content of bambo particleboards. The average MOR values of the bamboo binderlessboard manufactured at 200°C and 220°C were 5.2 and 5.3 MPa, respectively.

Compared to the previous results (Widyorini *et al.* 2011), it showed that the MOR of binderless-board in this study was relatively low. It might due to the differences between particle size and its size composition, as mentioned above.

After addition of the citric acid, the MOR values increased significantly as shown in Figure 3. All of the boards made from particles and citric acid had MOR that exceeded the minimum requirements for grade 8 type of JIS A 5908 for particleboards, i.e. 8.2 MPa. The maximum average MOR value was 12.5 MPa with 20 wt% citric acid content, and the specific MOR considering the density was 15.1 MPa. Umemura *et al.* (2011, 2012) found the same trend on the application of citric acid on wood and bark-molding product.

The MOR value decreased with increasing pressing time and pressing temperature, as the same trend to IB values. Figure 3 shows that increasing the pressing temperature resulted in decreasing MOR values. To produce the binderless particleboards, it took longer pressing time to get better properties. However, it clearly showed in Figure 3 that by adding the citric acid, the required pressing time becomes less. At 200°C pressing temperature and 10 min pressing time, it showed that addition of 10 (wt%) citric acid content in particles gave the higher MoR values.

Figure 4 shows relationship between MOE and citric acid content of bambo particleboards. The same trend to MOR values was also found, where addition of citric acid could improve the MOE values significantly. After addition of 20 wt% citric acid, the MoE value has improved almost 2 ~ 3 times at the same pressing condition. The maximum average MOE value was 4.1 GPa with a 20 wt% citric acid content, and the specific MOE was 4.6 GPa. All of the boards made from particles bonded with citric acid had MoE that

exceeded the minimum requirements for grade 13 type of JIS A 5908 for particleboards, i.e. 2.5 GPa. It showed that bamboo particleboards bonded using citric acid had high

performance on mechanical properties and good dimensional stability.

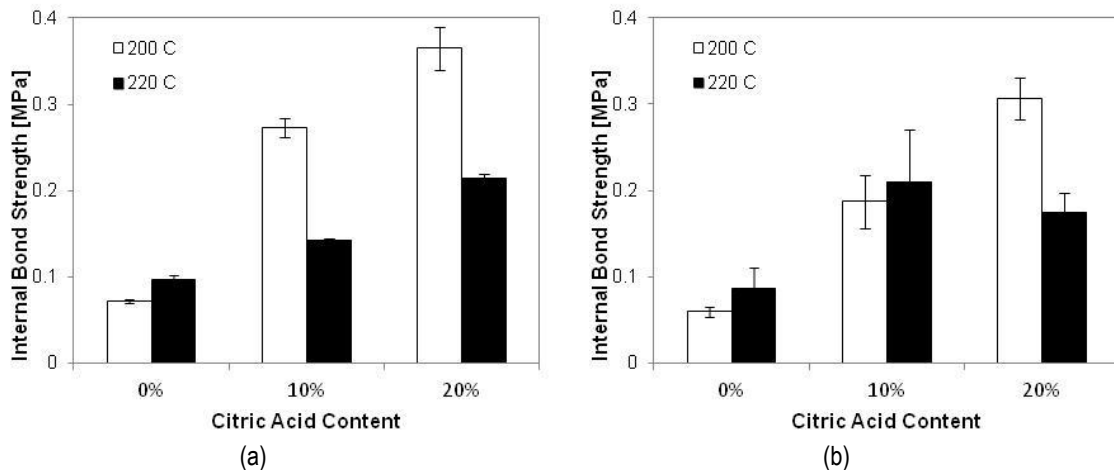


Figure 2. Relationship between internal bond strength and citric acid content of particleboards made from bamboo with pressing time (a) 10 min and (b) 15 min. Vertical lines through the bars represent the standard deviation from the mean.

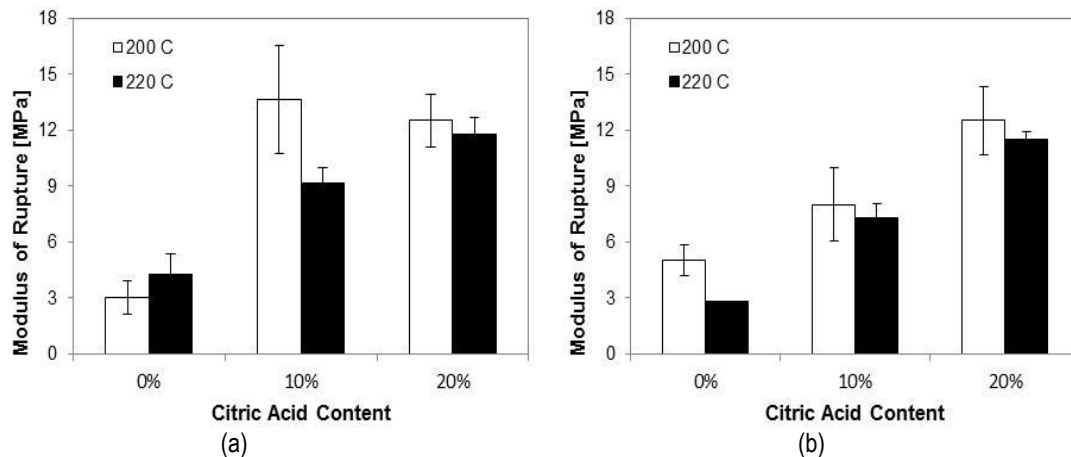


Figure 3. Relationship between modulus of rupture and citric acid content of particleboards made from bamboo with pressing time (a) 10 min and (b) 15 min. Vertical lines through the bars represent the standard deviation from the mean.

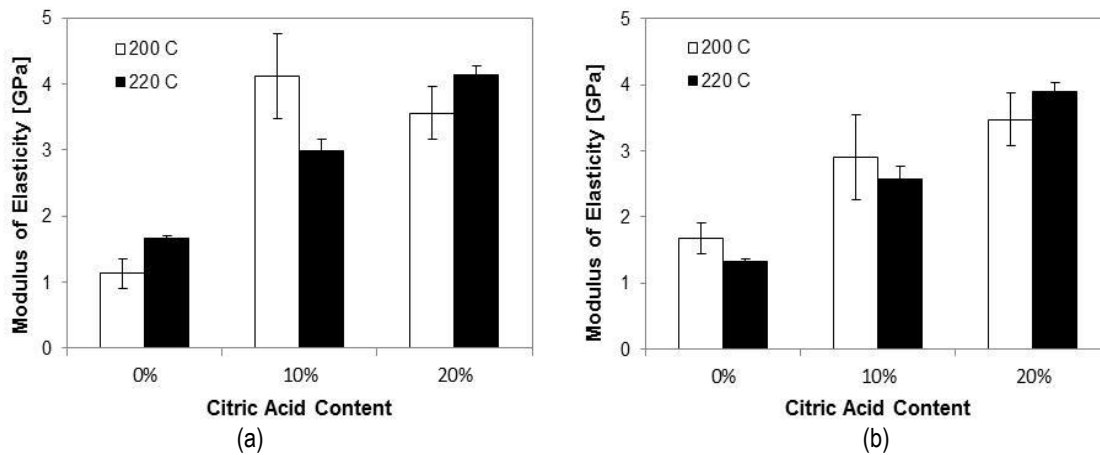


Figure 4. Relationship between modulus of elasticity and citric acid content of particleboards made from bamboo with pressing time (a) 10 min and (b) 15 min. Vertical lines through the bars represent the standard deviation from the mean.

Conclusions

The physical and mechanical properties of bamboo particleboards using citric acid on various pressing conditions were investigated. Bamboo particleboard can be manufactured by using the hot pressing system without any delamination. Addition of citric acid could improve the physical and mechanical properties of bamboo particleboard significantly. The mechanical properties of the boards decreased with increasing pressing time. The bamboo particleboards obtained had high properties, with the average specific IB, specific MOR and specific MOE values under the optimum condition of 20 wt % citric acid content, 200°C were 0.44 MPa, 15.1 MPa and 4.6 GPa, respectively. It stated that bamboo particleboards bonded using citric acid had high performance on mechanical properties and good dimensional stability.

Acknowledgments

This research was partly supported by research grant of Universitas Gadjah Mada 2012, Ministry of Education Indonesia.

References

- Dransfield, S.; E.A. Widjaja. 1995. Plant Resources of South-East Asia 7; Bamboos. Backhuys Publisers.
- Japanese Industrial Standard. 2003. JIS A 5908-2003 Particleboards. Japanese Standard Association, Tokyo
- Okuda, N.; M. Sato. 2004. Manufacture and Mechanical Properties of Binderless Boards from Kenaf Core. J Wood Sci. 50: 53-61.
- Sekino, N.; M. Inoue; M. Irlle; T. Adcock. 1999. The Mechanism Behind the Improved Dimensional Stability of Particleboards Made from Steam-pretreatment Particles. Holzforschung 53: 435-440.
- Suzuki, S.; H. Shintani; S.Y. Park; K. Saito; N. Laemsak; M. Okuma; K. Iiyama. 1998. Preparation of binderless boards from steam exploded pulps of oil palm (*Elaeis guineensis* Jaxq.) fronds and structural characteristics of lignin and wall polysaccharides in steam exploded pulps to be discussed for self-bonding. Holzforschung 52: 417-426
- Umemura, K.; T. Ueda; S.S. Munawar; S. Kawai. 2011. Application of Citric Acid as Natural Adhesive for Wood. J Appl Polym Sci. 123: 1991-1996
- Umemura, K.; T. Ueda; S. Kawai. 2012. Characterization of Wood-based Molding Bonded with Citric Acid. J Wood Sci. 58: 38-45
- Vukusic, S.B.; D. Katovic; C. Schramm; J. Trajkovic; B. Sefc. 2006. Polycarboxylic Acids as Non-formaldehyde Anti-swelling Agents for Wood. Holzforschung. 60: 439-444
- Widyorini, R.; J. Xu; T. Watanabe; S. Kawai. 2005a. Chemical Changes in Steam-Pressed Kenaf Core Binderless Particleboard. J Wood Sci. 51: 26-32.
- Widyorini, R.; J. Xu; K. Umemura; S. Kawai. 2005b. Manufacture and Properties of Binderless Particleboard from Bagasse I: Effects of Raw Material Type, Storage Methods, and Manufacturing Process. J Wood Sci. 51: 648-654.
- Widyorini, R.; A.P. Yudha; T.A. Prayitno. 2011. Some of the Properties of Binderless Particleboard Manufactured from Bamboo. Wood Research Journal 2(2): 89 – 93.
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