Carbon Dioxide Injection in Bamboo Cement Board Manufacturing

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Abstract

The objective of this study was to evaluate the effect of CO_2 injection in liquid phase to the physical and mechanical properties of cement board made from bamboo particles of *Gigantochloa atter*, *Dendrocalamus asper* and *Schizostachyium brachycla*. Mixtures of bamboo culm particles, cement, and water in the ratio by weight of 1:2.5:1.25 were casted in iron plate mold of (25x25x1) cm^3, pressed and then hold for 24 h to obtain the target density of 1 g cm^{-3}. The board was then injected by CO_2 in liquid phase for 30 min of curing time period. Evaluation of physical and mechanical properties of board were evaluated in accordance to JIS A 5417-1992 standard. The results showed that moisture content of the boards was 3.15-3.62%, density was 0.68-0.80 g cm^{-3}, water absorption and thickness swelling after immersed in cold water for 24 h were 45.11-57.60%, and 0.65-0.87%, respectively. The internal bond, modulus of elasticity and modulus of rupture were 0.18-0.74, 1339-5031, and 40.12-79.59 kg cm^{-2}, respectively. Only cement board made from mixture of *G. atter* particles, cement and water met physical properties requirement of JIS A 5417-1992 standard. However, no cement board fulfilled the mechanical properties requirement of JIS A 5417-1992.

Key words*:* bamboo, carbon dioxide injection, cement board

Introduction

The use of petroleum-based resins such as urea and phenol formaldehyde inconventional lignocellulosic-based composite boards has increased the production cost due to the gradual increasing of petroleum price. Also, emission of formaldehyde-based resins in panels has been known to cause eye, nose, and throat irritation as well as coughing and breathing difficulties. Alternative to replace petroleum-based binders is quite possible since many studies showed that the inorganic binders or ceramic materials such as Portland cement can be used as a potential matrix for lignocellulosic-based composite boards manufacturing.

The ability of portland cement to bind lignocellulosic materials is caused by the existence of certain chemical elements in Portland cement that can harden at certain temperature. The portland cement binder provides a durable surface and facilitate embossing and coloringwith a range of processing methods to provide a variety of products that are easily machined with conventional wood-working tools (Erakhrumen *et al*. 2008).

The use of lignocellulosic materials as aggregate such as wood has been widely used to produce cement boards for non-structural purposes such as walls and ceilings. However, since the growing concern of resource reduction of wood, many researchers seek and develop renewable sources new materials.

Bamboo is one of the most important raw materials to substitute wood due to its abundant, fast growing, and easy to be planted (Muin *et al.* 2006). As a cheap and fast-grown resource with superior physical and mechanical properties compared to that of most wood species, bamboo offers great potential as an alternative to wood.

The use of bamboo as raw material of cement board by using conventional technology has been researched by Suhasman and Bakri (2012). However, some characteristics of the resulted cement board have not been satisfying. Intensified research during the recent years has considerably contributed to the understanding of bamboo as well as to improved processing technologies for broader uses (Li 2008). Taking advantage of the wide distribution, renewability, and recyclability of bamboo, more markets will be developed forthese low-cost renewable materials.

Manufacturing of cement board composite is principally similar to that of conventional board composite. The variations only take place on the pressing time and the applied methods due to different type of binders. Manufacturing process of cement board composite is accomplished by mixing lignocellulosic material, portland cement, water and others supplementary materials and then pressed for consolidation. Pressing is held until 24 h to harden and densificate the board. Although densification and hardening condition of the board has been developed for 24 h, full strength of the board will be achieved at 28 days curing process.

Hardening process will be hampered and curing process will take longer time if the lignocellulosic materials contain large amount of hydrolysable hemiselluloses and extractive substances. The alkaline medium produced by cement dissolves the extractives and hemiselluloses which, in turn, react as retardant to cement (Moslemi1989). The effort to shorten the setting time was accomplished by the addition of accelerators (Simatupang *et al*. 1991).

Relatively new concept developed to speed up hardening process on cement board composite is to apply carbon dioxide injection into the cement board. This method was patented by British Patent in 1979 and Japanese Patent in 1986. Injection of CO_2 gas into the cement board results in calcium carbonate ($CaCO_3$) that increases early strength of cement board. This allows the removal of cement board from the mold just in several minutes.

CO_2 heating during pressing process of conblock manufacturing increased the resulting conblock strength (Berger *et al*. 1972). Injection of CO_2 gas into cement board shortened the pressing time (Simatupang & Geimer 1990). Hardening process reduced from 8 h to 5 min by CO_2 injection into the board and speed up the production (Lahtinen 1991). CO_2 injection into cement board reduced inhibitory effect of several wood species to cement hydration (Moslemi *et al*. 1993). The use of CO_2 injection in supercritical gas phase to reduce curing time in cement board manufacturing increased some physical and mechanical properties of board (Hermawan 2001a).

Materials and Methods

Materials

All of bamboo species used in this research was taken from Maros regency, province of South Sulawesi. About 1-2 years old of parring bamboo (*Gigantochloa atter*), tallang bamboo

(*Schizostachyium brachycladum)*, and betung bamboo (*Dendrocalamus asper*), culms were grinded in mill refiner to obtain particles that pass through a 10 mesh screen and retained on a 40 mesh screen for measurement of hydration temperature. The core layer of cement board composed of particles that passed a 10 mesh screen and retained on 20 mesh screen.The face and back layers of the boards were prepared from particles that passed a 20 mesh screen and retained on 40 mesh screen. Type I commercial portland cement (available on the local market in Makassar) was used as matrix or binder.

Hydration temperature measurement

The ratio of bamboo particles, portland cement, and water mixture was 1: 13.3:6.65. The resulting slurry was then stirred to a homogenous paste (Hermawan 2001b). The paste was poured into a plastic glass and put into air tight styrene foam container. A thermometer in glass tube (contained barco oil) was put into styrene foam container through a hollow at container cap. Hydration temperature was recorded every 1 h interval for 24 h during the hydration process. The *S. brachycladum* particles, portland cement and water mixture; *G. atter* particles, portland cement and water mixture; and *D. asper* particles, portland cement and water mixture were assigned as A, B, and C mixture, respectively.

Board manufacturing and CO_2 injection

Cement board was manufactured by mixing bamboo particles, portland cement and water in the ratio of 1:2.5:1.25. Targeted density of the cement board was 1 g cm^{-3} and targeted thickness was 1 cm. Finer particles that passed a 10 mesh screen and retained on 20 mesh screen were used for face and back layers, while coarser particles passing a 5 mesh screen and retained on 10 mesh screen were used for core layer of the manufactured cement board. Particles size ratio of face:core:back was 15:7:15%.

Bamboo particles were immersed in water for 48 h to remove the extractives and dried in room temperature until reaching moisture content of ±30%. Bamboo particles, portland cement and water were stirred to a homogenous mixture. The mixture was then poured into iron plate of (25x25x1) cm^3 covered by plastic sheet and pressed for 24 h during the setting time. The mixture was converted to solid cement board after setting time was completed.

Injection of CO_2 in liquid phase into the cement board was carried out for 30 min for curing. Sample of cement board was put into the injection tube to where the CO_2 was injected. Liquid phase of CO_2 was reached by setting the tube temperature at 15 ^oC and tube pressure at 50 kg cm^{-2} for 30 min. Cement board was removed from the tube and put into desicator for 15 minutes. Cement board was weighed and put into oven for the next curing at 80 ^oC for 10 h.

Testing

The physical and mechanical properties of boards were determined according to Japanese Industrial Standard JIS A 5417-1992 (JAS 1992). The physical properties of board (i.e. density, moisture content, water absorption, thickness swelling, and linear expansion), and mechanical properties of board (i.e. modulus of rupture, modulus of elasticity, and internal bond) were determined.

Results and Discussion

Hydration temperature

Figure 1 indicates the curve of the hydration temperature of the bamboo particles, cement and water mixture during the hydration process. The maximum hydration temperature of the A, B, and C mixture was 39, 38, and 34 ^oC, respectively. Based on Kamil Classification (1970), maximum hydration temperature of all samples was categorized as low. It can be observed from Figure 1 that each bamboo species reacted differently with portland cement. Although time required to reach maximum hydration temperature by the mixture of C was shorter (3 h) than these of B (7 h) and A(9 h), but maximum hydration temperature of A was higher (39 ^oC) than these of B and C.

Low maximum hydration temperature of all mixtures can be affected by the high content of hemicelluloses and extractives of bamboo particles. The compatibility of cement and lignocellulosic materials on the hydration process is influenced by hemicelluloses and extractive content of lignocellulocic materials. Hydration process will be disturbed if cement is mixed with materials containing high content of hemicelluloses and extractives due to the declining of exothermic reaction when hydration temperature is released. Hemicelluloses content, calculated from the difference between holocellulose and alpha cellulose content, of *G. atter* was higher (29.37%) than those of *D. asper* (28.65%) and *S. brachycladum* (27.66%) and also extractive content (soluble in ethanol-benzene) of *G. atter* was higher (4.93%) than those of *D. asper* (4.10%) and *S. brachycladum* (3.43%) (Laiwatu & Manuhuwa 2008, Baharuddin 2013).

Physical properties

The physical properties of the currently resulting cement boards are shown on Table 1. It can be observed from Table 1 that cement board made from B mixture had most excellent physical properties.

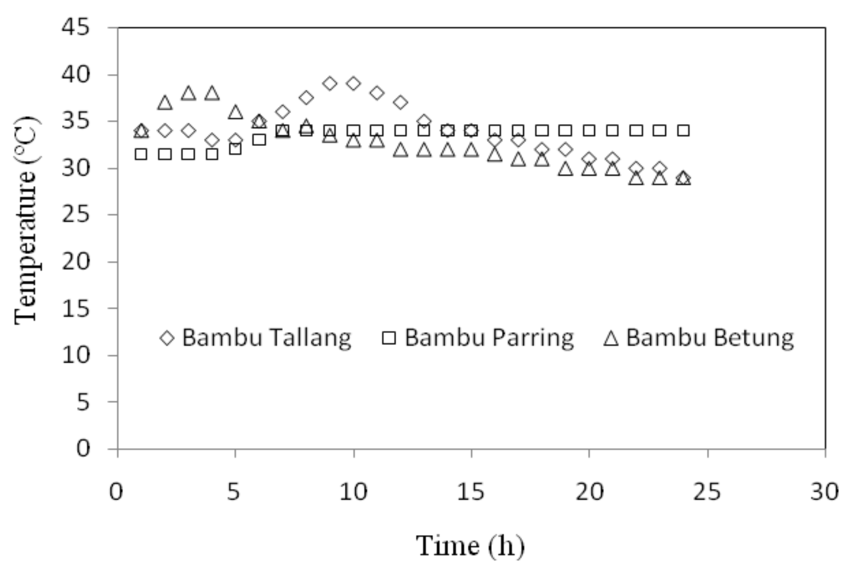

Figure 1 Hydration temperature of bamboo, cement, and water mixture.

Table 1 shows that moisture content and density of the cement boards for the mixture of A, B, and C was 3.25, 3.15, and 3.62%; and 0.74, 0.80, and 0.68 g cm^{-3}, respectively.

Cement board density can be affected by the density variation of culm of each bamboo species. In this study, higher density of bamboo species resulted in a higher density of the cement board. Culm density of *S. brachycladum* was 0.69 g cm^{-3}, *G. atter* was 0.79 g cm^{-3} and *D. asper* was 0.62 g cm^{-3}.

The present study indicated that all mixtures resulted in cement board density that did not satisfy the targeted density of 1 g cm^{-3}. This possibly was due to that although setting time of the hydration process of the mixture was completed for 24 h, however remaining water held in the cement boards was still use for hydration process to produce maximum amount of calcium silicate hydrate during the next 28 days curing in room temperature. Restriction of the curing period to 30 minutes at 80 ^oC resulted in evaporation of remaining water due to the high temperature so that maximum amount of calcium silicate hydrate can not be attained and this did not bring about the desired weight of the cement boards. It was supposed to raise the weight of cement boards to complete the targeted density of 1 g cm^{-3} by the presence of $CaCO_3$ resulted from reaction of CO_2 injection and $Ca(OH)_2$. However, the formation of additional $CaCO_3$ failed to increase the board weight that satisfy the requirement of cement board density of the JIS A 5417-1992, which is of greater than 0.8 g cm^{-3}. Small difference between density of bamboo culm and density of cement board described that density of cement board was mostly influenced by density of bamboo culm. The density of cement board may not significantly be influenced by the presence of hydration products such as calcium silicate hydrate and calcium carbonate.

Table 1 shows also that water absorption, linear expansion and thickness swelling varied between the cement boards. Water absorption of the cement boards can be directly affected by the percentage of cavity volume in the bamboo particles. The percentage of cavity volume in the bamboo particles can be estimated from the bamboo culm density showing that the highest to the lowest percentage of cavity volume were in *D. asper, S. brachycladum* and *G. atter* particles. This result noticed that particles of the 3 bamboo species were very higroscopic material because of their high ability to absorp water. Matoke *et al*. (2012) confirmed that water absortion of bamboo is a disadvantage for composite. This study showed that the highest to the lowest water absorption respectively were obtained from cement board prepared from mixture C (57.60%), mixture A (49.20%) and mixture B (45.11%).

Table 1 Physical properties of the bamboo cement boards

Cement board	MC (%)	Density ($g\ cm^{-3}$)	WA (%) 24 h	LE (%) 24 h	TS (%) 24 h
Mixture A	3.25	0.74	49.20	0.19	0.87
Mixture B	3.15	0.80	45.11	0.13	0.65
Mixture C	3.62	0.68	57.60	0.27	1.35

Note: MC: Moisture content; WA: Water absorbtion; LE: Linear expansion; TS: Thickness swelling.

This study also found that the density of cement boards was inversely related to the water absorption. Although JIS A 5417-1992 does not include water absorption for cement board requirement, it can be used as good prediction to the linear expansion and thickness swelling behavior. As a hygroscopic material, bamboo culm particles absorp water to fill the lumen cell and cell wall. When the cell wall absorbs water, cell wall expands depending on the amount of water absorbed.

As shown in Table 1, linear expansion and thickness swelling of the cement boards was likely to follow the water absorption trend. Although percentage of water absorption of the cement boards can be rated as high enough, percentage of linear expansion and thickness swelling of cement boards were extremely low. While requirement of thickness swelling of cement board by JIS A 5417-1992 is lower than 8.3%, it can be observed that cement boards made from all of the 3 mixtures were dimensionally stable. The presence of $CaCO_3$, as a result of reaction between CO_2 and $Ca(OH)_2$ filled the tiny cavity in the cell wall or even covered the bamboo particles, together with other hydration products may have controlled the cement boards from swelling.

Mechanical properties

Mechanical properties of the resulting cement boards of the present works are shown in Table 2. In contrarily to the physical properties, it was observed that the most excellent mechanical properties of cement board were found for the mixture of A.

Table 2 shows that internal bonding, modulus of elasticity and modulus of rupture of cement board made from the mixture of A was superior than these of cement boards made from other mixtures. In many cement board products, density of cement board can be used as a good indicator to the mechanical properties. The higher the density of the cement board, the better the mechanical properties. As previously stated in this study, higher density of bamboo species resulted in higher density of the cement board. It can be theoretically simply explained that higher density of bamboo particles contains smaller volume on the equal weight of different bamboo particles.

If it is assumed that calcium silicate hydrate produced in the hydration process was in equal amount for all cement boards of different mixture, there will be higher amount of calcium silicate hydrate to cover the particles or fill the cell cavity and cell wall of the higher density cement boards in order to better improve the mechanical properties. However, this was not realized in the cement board prepared from the mixture of B although it had the highest density.

Table 2 Mechanical properties of the bamboo cement boards

Cement Board	IB (kg cm^{-2})	MOE (kg cm^{-2})	MOR (kg cm^{-2})
Mixture A	0.74	5030.50	79.59
Mixture B	0.41	2338.82	49.75
Mixture C	0.18	1339.03	40.12

Note: IB: Internal bond; MOE: Modulus of elasticity; MOR: Modulus of rupture.

On contrarily to the B mixture cement board, although cement board of the A mixture had lower density; it showed better mechanical properties than the other mixtures. At least, only one main reason to explain this phenomenon.

As shown by the hydration temperature curve in Figure 1, the highest maximum hydration temperature was for the A mixture cement board specifying that bonding ability of this mixture was better than the other mixtures. This better bonding ability was influenced by the lower content of hemicelluloses and extractives of *S. brachycladum* particles. It might be predicted that the amount of calcium silicate hydrate after hydration process and $CaCO_3$ after injection of CO_2 was higher in the A mixture cement board than these of the other mixtures. The higher the calcium silicate hydrate and the calcium carbonate in the cement board, the better the mechanical properties.

It was observed from the mechanical properties that application of CO_2 injection to the cement board in this study has not mostly satisfied the JIS A 5417-1992. Even though it was desired that higher amount of $CaCO_3$ was produced after injection of CO_2, however this seemed was not coming true. Production of $CaCO_3$ from CO_2 injection depends on the amount of $Ca(OH)_2$ that is resulted from hydration process of water and cement. If the hydration process is hampered by many factors including the presence of hemicelluloses and extractives, less $Ca(OH)_2$ will be produced. Whereas JIS A 5417-1992 requires modulus of rupture of $\geq$63 kg cm^{-2} and modulus of elasticity of $\geq$ 24000, only the modulus of elasticity of A mixture cement board satisfied the JIS requirement.

Conclusion

Physical and mechanical properties of cement board made from different mixture of bamboo particles, cement and water and application of CO_2 injection were depending on bamboo species. Only cement board made from mixture of *G. atter* particles, portland cement and water satisfied the physical properties requirement of JIS A 5417-1992 and no cement board satisfied mechanical properties requirement of JIS A 5417-1992. This indicates that application of CO_2 injection in liquid phase in this study has not been able to effectively controlling desirable physical and mechanical properties of the bamboo cement board.

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