Dimensional Stability and Mechanical Properties of Strandboard Made from Bamboo

Ihak Sumardi [a,]* and Shigehiko Suzuki [b]

Dimensional changes in bamboo strandboard could decrease the bond durability, causing problems for structural materials. Thus, it is critical and of practical importance to study the relationship between thickness swelling (TS) and internal bond (IB) strength loss on bamboo strandboard. To determine the relationship between dimensional stability and bond durability of bamboo strandboard, various densities and board types were examined. The results show that board density and board types affected TS and water absorption (WA). The board with lower density was easier to swell than that of higher density. The board density influenced the TS/WA ratio for short-term water soaking, but not for long-term water soaking. For layer-structured board, the TS/WA ratio of randomly oriented homogenous board (RAND board) was slightly higher than that of uni-directionally oriented homogenous (UNID), three-layered oriented strandboard with cross-oriented core layer (3LYC), and three-layered oriented with random core (3LYR) boards. The maximum swelling can only be reached by high-temperature water soaking. The IB strength loss of UNID board was higher than that of RAND board.

Keywords: Thickness swelling; Internal bond; Bamboo; Strandboard; Dimensional stability

*Contact information: a: School of Life Sciences and Technology, Institut Teknologi Bandung, Jalan Ganesha 10 Bandung Indonesia; b: Wood Science, Faculty of Agriculture, Shizuoka University, Japan; * Corresponding author: ihak@sith.itb.ac.id*

INTRODUCTION

Dimensional stability is an important property in the use of oriented strandboard (OSB). Oriented strandboard, when used as wall sheathing, is required to have good dimensional stability in both in-plane and vertical directions. In-plane swelling, which is known as linear expansion (LE), can be a very significant factor affecting the state of stress that exists in the material in both structural and non-structural utilization. LE is a phenomenon whereby there is only small change in the in-plane direction; however, it sometimes causes a serious problem for OSB in structural applications. Swelling in the vertical (thickness) direction is also a problem for wood-based panels, as it adversely affects OSB bond durability.

In the past few decades, special attention has been paid to the dimensional stability of wood-based material. Many studies have been conducted with respect to such issues as the relative humidity of the surrounding environment (Bryan 1962), the influence of processing variables on the plane behavior of single oriented strandboard (Wu 1999), the dimensional stability in the in-plane direction of plywood, waferboard, and OSB (Zylkowski 1986, 1989), thickness swelling molded at various humidity of fiberboard and fiber/polymer composites (Shia and Gardnerb 2006), and the LE of medium-density fiberboard (Suchsland and Xu 1991). However, very limited work has been done directly relating to thickness swelling (TS) and its relationship to internal bond (IB) strength. Wu (1999) reported the in-plane dimensional stability of commercial strandboards using a mixture of hardwood and southern pine as raw materials. Some research that use bamboo as materials focus on various composite panels such as zephyr board (Nugroho and Ando 2000), particleboard (Zhang *et al.* 1997), and oriented strandboard (Lee 1996 and Sumardi *et al.* 2006). To date, there has been little published information on the thickness swelling of OSB made from bamboo. Thus, it is critical and of practical importance to study the relationship between TS and IB strength loss for bamboo OSB.

The objective of this study was to obtain information about manufacturing variables that affect the dimensional stability using various characterization techniques. The relationship between TS and IB strength loss is also discussed in this study.

EXPERIMENTAL

Strand Preparation and Board Fabrication

Bamboo strands were produced from freshly cut moso bamboo (*Phyllostachys pubescens*) using a laboratory ring-type flaker. The density of the bamboo raw material was approximately 0.60 g/cm^3. The dimensions of the target strands were 40 mm in length, 0.5 mm in thickness, and 5 to 20 mm in width. All strands were initially screened on a 10-mesh sieve and then dried in an oven at 60 °C to a moisture content of less than 3% prior to adding adhesive. Randomly oriented homogenous boards (RAND) of 370 mm x 370 mm x 12 mm were fabricated at five density levels ranging from 0.49 to 0.81 g/cm^3. A commercial liquid, diphenylmethane diisocyanate (MDI) with 6% resin content, was applied to strands using a pressurized spray gun in a box-type blender. No waxes or other additives were applied. Hand-formed mats were pressed at a temperature of 180 ^{o}C for 10 min; the maximum pressure applied was 2.5 MPa. No surface sanding was performed.

Three additional types of board at a density of 0.65 g/cm^3 were fabricated at the same conditions (Table 1), with different layer structures: uni-directionally oriented homogenous boards (UNID); three-layered oriented strandboards with cross-oriented core layers (3LYC); and three-layered oriented strandboards with randomly oriented core layers (3LYR). The face/core/face ratio was 1:2:1 based on the dried weight of strands. Four panels were produced for each treatment condition.

Table 1. Board Types for Experiment

Board type	Density (g/cm^3)	Layer
RAND	0.49	homogenous
	0.57	homogenous
	0.65	homogenous
	0.73	homogenous
	0.81	homogenous
UNID	0.65	homogenous
3LYC	0.65	3-layers
3LYR	0.65	3-layers

Measuring Dimensional Changes

Prior to testing, all boards were conditioned at a relative humidity (RH) of 65% and a temperature of 25 ^{o}C for at least 2 weeks. Two different types of TS test were conducted. One was according to the Japanese Industrial Standard (JIS 1994) for particleboard. The samples with dimension of 50 mm by 50 mm were soaked in 20 ^{o}C water for 2 h (T2), and then soaking was continued for 24 h (T24). The swelling and water absorption (WA) were measured for each level. Another test of TS was conducted on a wet-dry cycle. For the wet-dry cyclic test, the specimens were subjected to dimensional stability evaluation under the following wet-dry conditioning cycles. During the first cycle of this process, boards were soaked in 20 °C water for 24 h (W1) and then they were oven-dried at 50 °C for 22 h (D1). During the second cycle, the boards were soaked in 70 °C water for 2 h (W2) and then oven-dried at 50 °C for 22 h (D2). During the third cycle, the boards were soaked in 100 ^{o}C water for 2 h (W3) and oven-dried at 50 °C for 22 h (D3). After these treatments, specimens of 50 mm by 50 mm were conditioned at 25 °C and 65% ± 5% RH until they reached equilibrium. The thickness changes of the boards were calculated based on initial measurements taken after the boards were dried at 60 °C for 22 h. Eight replicates for each condition were used.

The dimensional stability in the in-plane direction was evaluated by measuring the LE. Two specimens with dimensions of 300 mm x 50 mm were tested. Changes in length were regularly measured during treatment in humid conditions of 90% RH at 40 °C for 150 h using a dial gauge comparator (ASTM 1988). The LE was calculated based on initial measurements taken after the boards were dried at 60 °C for 22 h.

Internal Bond Strength and Density Profile

The internal bond (IB) test was conducted according to the Japanese Industrial Standard (JIS 1994) for particleboard. Eight 50 mm x 50 mm specimens were prepared for the test. Before the IB test, the density profile across the board thickness for each specimen was measured with a densitometer (commercial density profiler).

RESULTS AND DISCUSSION

It is well known that the density profile of a board strongly affects the bending and dimensional properties (Kelly 1977). Different density gradients were observed for panels with different mean densities, as shown in Fig. 1. Boards with densities between 0.50 and 0.58 g/cm^3 did not have a typical density gradient because of the lower compaction ratio of the panels.

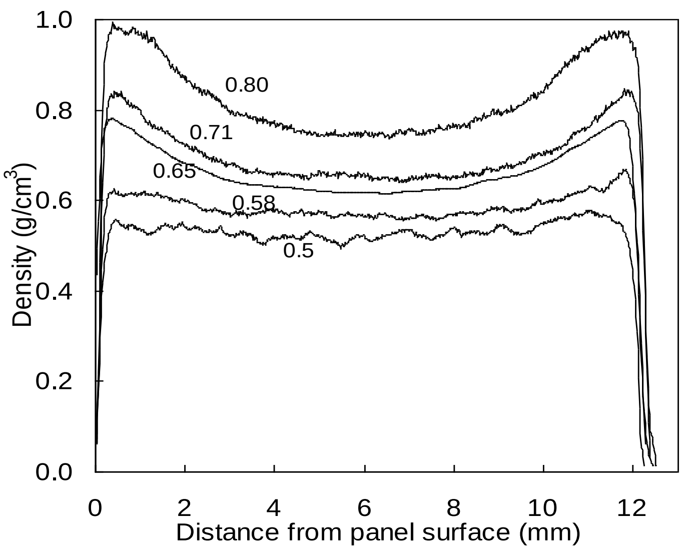

Fig. 1. Density profiles of bamboo strandboards with different mean densities

For higher-density panels, the shapes of their density gradients were similar to a typical density gradient for particle board with high-density layers at board surfaces. The density gradients of layer-structured panels (*i.e.*, UNID, 3LYC, and 3LYR) showed similar peak densities and core densities of 0.73 g/cm^3 and 0.60 g/cm^3, respectively.

Thickness Swelling and Water Absorption

Table 2 summarizes the results of TS and water absorption (WA) at various densities after 2 and 24 h of water soaking for RAND board. TS decreased with increasing board density after 2 and 24 h water soaking, whereas the ratio of TS to WA (TS/WA) increased at 2 h of water soaking. This indicated that low-density panels swelled more easily than higher-density boards, and the low-density boards showed more WA than did high-density boards.

Table 2. Water Soaking Results for Bamboo OSB with Different Densities of RAND Board

Board density (g/cm^3)	TS (%)		WA (%)		TS/WA	
	2 h	24 h	2 h	24 h	2 h	24 h
0.49	3.40	7.60	33.02	59.65	1.48	0.13
0.57	2.72	6.85	24.06	52.94	2.37	0.13
0.65	1.07	5.19	10.34	39.34	6.29	0.13
0.73	1.05	3.19	9.47	23.61	7.71	0.14
0.81	1.03	2.63	6.67	18.31	12.15	0.14

TS: thickness swelling; WA: water absorption

The TS/WA ratio from low to high density increased with increasing density for 2 h of water soaking. For 24 h of water soaking, the TS/WA ratio was relatively constant at 0.13 to 0.14 %/% (Table 2). This indicated that the board density had a significant effect on the TS/WA ratio for short-term water soaking and was insignificant for long-term water soaking. Wood swells extremely fast in water even at room temperature, this apparatus made it possible, for the first time, to obtained accurate rate data on the swelling of wood in water (Mantanis 1994). It was hypothesized that the free void water absorbed into the test specimens increased the WA, but had less effect on the swelling, and the amount of swelling was proportional to the density.

It has been shown that density has a great influence on the TS properties of OSB (Winistorfer and Xu 1996). It is also known that high-density boards have high compaction ratios and can absorb more water than low-density boards at equilibrium. Furthermore, the reduced porosity in the high-density boards prevented rapid liquid water penetration throughout the board. Consequently, in high-density material, the diffusion path of water into the individual component flakes was much longer and the subsequent rate was reduced (Kelly 1977).

The TS after 2 and 24 h of water soaking of 0.65-g/cm^3 boards reached 1% and 5%, respectively, as shown in Fig. 2. The random boards showed slightly higher TS values than did UNID, 3LYR, and 3LYC boards for both soaking conditions. This indicated that the pressure release of random boards was higher than that of the other types of boards. This result was also supported by the TS/WA ratio after 24 h of water soaking, with values ranging from 0.11 to 0.13 %/%. All TS values of the boards were far below 15% of the maximum TS required by the CSA proposed standard, and were much lower than those reported by Avramidis and Smith (1989).

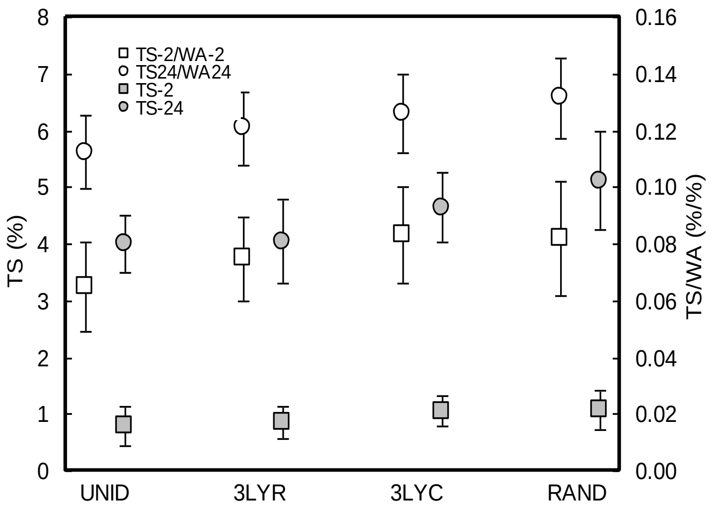

Fig. 2. Effect of layer structures on thickness swelling (TS) and TS/WA ratio of bamboo strandboard with a density of 0.65 g/cm^3. TS-2: thickness after 2 h of water soaking, TS-24: thickness after 24 h of water soaking

Thickness Swelling Aging Treatment

Figure 3 shows the thickness swelling obtained though wet-dry cyclic treatment. Those tests were conducted to obtain variations respond of swelling from low treatment (water soaking) up to extreme treatment (boiling water soaking). TS increased with increasing treatment cycles for all densities. For a density of 0.49 g/cm^3, the TS was 8, 12, and 14% for W1 (water soaking), W2 (hot water soaking), and W3 (boiling water soaking), respectively.

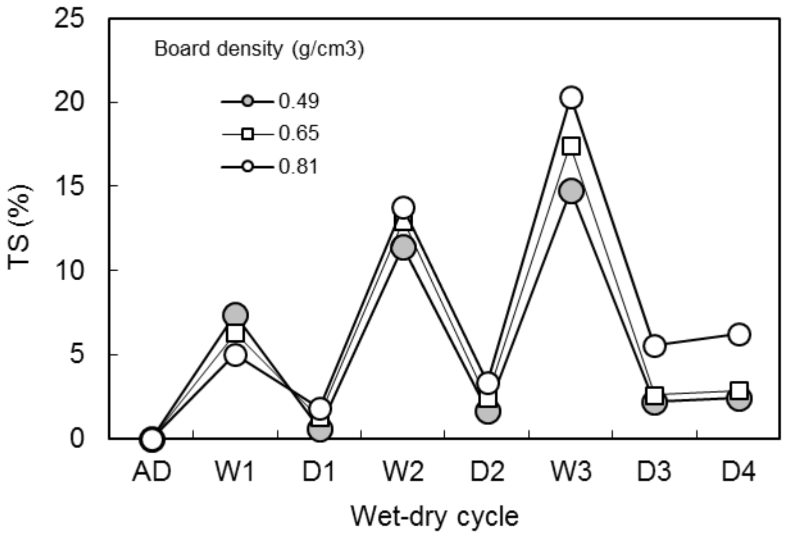

Fig. 3. Effect of board density on thickness swelling (TS) tested under a cycle of wet-dry aging treatment for random boards. First cycle: soaked in water at 20 °C for 24 h (W1) and oven-dried at 50 °C for 22 h (D1); second cycle: soaked in water at 70 °C for 2 h (W2) and oven-dried at 50 °C for 22 h (D2); third cycle: soaked in boiling water for 2 h (W3) and oven-dried at 50 °C for 22 h (D3). After these treatments, the specimens were conditioned at 25 °C and 65% ± 5% RH until equilibrium was reached (D4).

For the W1 condition, the TS increased with decreasing density. However, the reverse trend was observed for the W2 and W3 conditions; namely, the TS of the board with a density of 0.81 g/cm^3 was larger than that with a density of 0.49 g/cm^3. The 24-h water soaking treatment for bamboo strandboard using MDI resin may not be long enough to result in maximum swelling for the higher-density board (Table 1). It is well known that MDI resin has higher durability than phenol resin at high humidity (Galbraith 1986). However, a TS value of 4 to 7% after aging treatment is relatively good performance for bamboo strandboard.

Hot Water Soaking Treatment

To determine the maximum swelling of bamboo strandboard, the hot water soaking treatment test was conducted with RAND boards at a density of 0.65 g/cm^3. The samples were soaked in hot water at various temperatures for 2 h, followed by cold water soaking for 24 h and drying at 60 ^{o}C for 72 h. The thickness and weight were measured for each step to demonstrate the manner in which the board swelling increased.

Figure 4 shows the effect of temperature on TS for different water soaking processes. The TS increased with increasing temperature for 2 h of hot water soaking, whereas for the 24-h treatments, the TS at 20, 40, and 60 ^{o}C showed similar results of approximately 7%, and increased at 80 and 100 ^{o}C. It is obvious that the maximum swelling could not be obtained through cold water soaking. It can be only reached by soaking at high temperatures, and the increasing temperature usually increases water sorption of woods (Sahin 2008). Temperature also has a significant effect on the hygroscopic thickness swelling rate (Shia 2006). On the contrary, the thickness and weight loss of specimens after drying decreased with increasing temperatures. The TS decreased to -1% and the weight loss decreased to -5.5% for treatment at 100 ^{o}C, as shown in Fig. 4 (right).

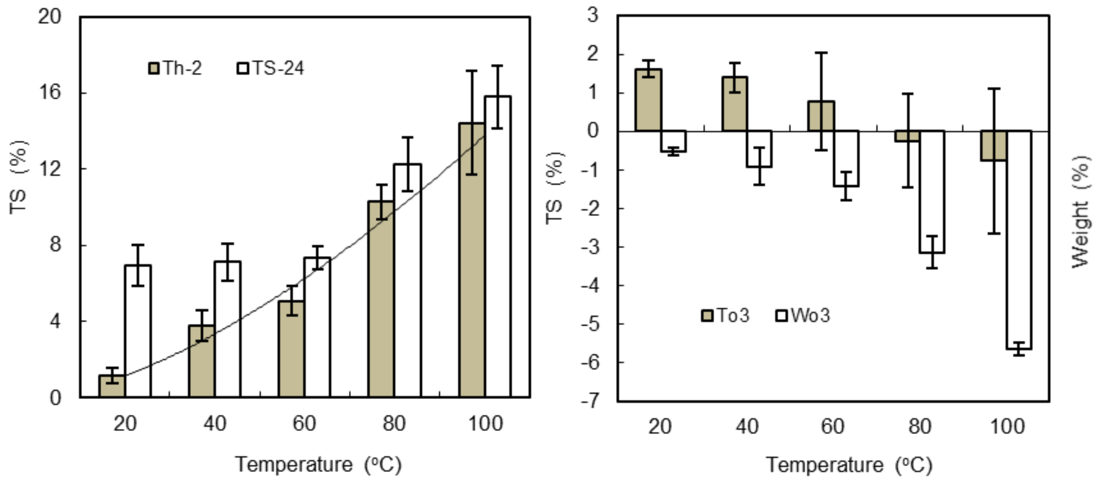

Fig. 4. Effect of water soaking temperature on thickness swelling (TS). TS-2: thickness swelling after 2 h of water treatment, TS-24: TS after 24 h soaking in cold water, To3: TS after drying at 60 °C for 3 days, Wo3: weight loss after drying at 60 °C for 3 days.

In-Plane Stability

Another aspect of the dimensional stability of strandboards for structural purposes is the in-plane stability. Figure 5 shows the LE behavior at various densities after the humidity test at 40 °C and 90% RH for 150 h. LE values for all densities increased rapidly at the beginning of the humidity test and leveled off as they approached the saturation point. The LE of the panels with a density of 0.49 g/cm^3 seemed to reach its saturation value at around 10 h, whereas the panels with a density of 0.81 g/cm^3

continually increased after 50 h. This resulted in the same trend that has been found for TS of fiberboard subjected to humidity conditions; the different humidity conditions gave rise to specific saturation points (Shia 2006). Figure 5 also shows that the LE saturation value increased with board density, as well as the time to reach the saturation point.

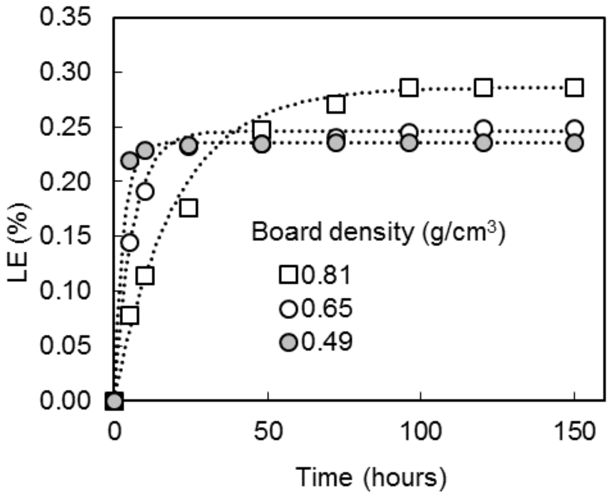

Fig. 5. LE behavior of randomly oriented bamboo OSBs with different densities under condition of 40 °C and 90% RH

Thickness Swelling and Internal Bond (IB)

It is well known that TS values are closely related to IB strength. Table 3 summarizes the TS and IB strength at various layer structures with a constant board density of 0.65 g/cm^3. The TS value was obtained through 24-h water soaking (TS-24), followed by drying at 60 °C for 24 h to obtain the IB (IB-24). The strength reduction of IB (ΔIB) was defined as the difference between the IB-24 and the IB at the control conditions.

Table 3. Thickness Swelling (TS) and Internal Bond (IB) Strength Reduction for Various Layer Structures

Board Type	TS-24 (%)	IB-24 (MPa)	IB (MPa)	ΔIB (MPa)	ΔIB/TS-24 (MPa/%)
RND	5.12 (0.86)	0.75 (0.17)	1.35 (0.12)	0.60	0.117
UNID	4.00 (0.51)	0.90 (0.91)	1.41 (0.11)	0.51	0.129
3LYR	4.05 (0.73)	0.87 (0.20)	1.36 (0.09)	0.49	0.121
3LYC	4.64 (0.61)	0.79 (0.16)	1.35 (0.11)	0.55	0.119

TS-24: Thickness after 24 h of water soaking, IB-24: internal bond strength after 24 h of water soaking, IB: internal bond strength at control conditions, ΔIB: difference between IB and IB-24. Numbers in parentheses are standard deviations from the sample mean.

The results showed that the strength reduction of IB per unit of thickness swelling change (ΔIB/TS-24) of UNID boards was higher than that of RAND boards (Table 3). The ΔIB/TS-24 were 0.129 and 0.117 MPa/% for the UNID and the RAND boards, respectively. This phenomenon indicates that UNID board has the highest sensitivity, and the small change in thickness swelling can reduce the higher internal bond strength. It seems likely that parallel-oriented strands at UNID board might provide better contact and bond quality than in randomly formed strands. However, it should be noted that the ΔIB/TS-24 could also be affected by other parameters, such as resin type, board density, and particle geometry.

CONCLUSIONS

1. The board density and layer structure affected TS and WA. Boards with lower densities were easier to swell than those with higher densities. The board density influenced the TS/WA ratio for short-term water soaking, but not for long-term water soaking.
2. For layer-structured boards, the TS/WA ratio of RAND boards was slightly higher than those for UNID, 3LYR, and 3LYC boards.
3. The maximum swelling can only be reached using high-temperature water soaking. The IB strength loss of UNID boards was higher than that of RAND boards. However, boards with higher densities required more time to reach LE saturation values than did boards with lower densities.
4. The ΔIB/TS-24 ratio could be used as an indicator to evaluate internal bond reduction by dimensional change.

REFERENCES CITED

Avramidis, S., and Smith, L. A. (1989). "The effect of resin content and face-to-core ration on same properties of oriented strandboard," *Holzforschung* 42(2), 131-133.
Bryan, E. L. (1962). "Dimensional stability of particleboard," *Forest Prod. J.* 12(12), 572-576.
Canadian Standard Association. (1992). "Standard on OSB and waferboard," CAN/CSA 0437-92. CSA, Rockdale, ON.
Galbraith, C. J. (1986). "Recent development in the full-time manufacture of all-isocyanate bonded structural composite boards," *Proceedings of the 20th International Particleboard/Composite Materials Symposium*, Washington State University, Pullman, WA. pp. 59-78.
Kelly, M. W. (1977). "Critical literature review of relationships between the processing parameters and physical properties of particleboard," *General Technical Report FPL-10.* U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, Madison, WI.
Lee, A. W. C., Bai, X, and Peralta, P. N. (1996). "Physical and mechanical properties of strand board made from moso bamboo," *Forest Prod. J.* 46, 84-88.
Mantanis, G. I., Young, R. A., and Rowell, R. M. (1994). "Swelling of wood, Part 1. Swelling in water," *Wood Sci. Technol*. 28 (2), 119-134.

Nugroho, N., and Ando, N. (2000). "Development of structural composite product made from bamboo I. Fundamental properties of bamboo zephyr board," *J. Wood Sci.* 46, 68-74.
Sahin, H. T. (2008). "Wood-water interaction as affected by chemical constituents of woods," *Asian Journal of Chemistry* 20(4), 3267-3276.
Shia, S. Q., and Gardnerb, D. J. (2006). "Hygroscopic thickness swelling rate of compression molded wood fiberboard and wood fiber/polymer composites," *Composites Part A*: 37(9), 1276-1285.
Suchsland, O., and Xu, H. (1991). "Model analysis of flakeboard variables," *Forest Prod. J.* 41(11-12), 55-60.
Sumardi, I., Suzuki, S., and Ono, K. (2006). "Some important properties of strandboard manufactured from bamboo," *Forest Prod. J.* 56, 59-63.
Winistorfer, P. M., and Xu, X. (1996). "Layer water absorption of medium density fiberboard and oriented strandboard," *Forest Prod. J.* 46(6), 69-72.
Wu, Q. (1999). "In-plane dimensional stability of oriented strand panel: Effect of processing variables," *Wood Fiber Sci.* 31(1), 26-40.
Zhang, M., Kawai, K., Yusuf, S., Imamura. Y., and Sasaki. H. (1997). "Manufacture of wood composite using lignocellulosic materials and their properties III. Properties of bamboo particleboards and dimensional stability improvement using a steam-injection press (in Japanese)," *Mokuzai Gakkaishi* 43, 318-326.
Zylkowski, S. C. (1986). "Dimensional stability of structural-use panels," *American Plywood Assoc. Res. Report No. R & D 86L-43*. Tacoma, WA, p. 16.
Zylkowski, S. C. (1989). "Dimensional performance of wood based siding," *American Plywood Assoc. Res. Report No. 149*, Tacoma, WA, p. 50.

Article submitted: October 11, 2013; Peer review completed: December 10, 2013; Revised version received: December 20, 2013; Accepted: December 21, 2013; Published: January 9, 2014.