Effects of Bamboo Species, Steam-heating Treatment, and Adhesives on Mechanical Properties and Dimensional Stability of Oriented Bamboo Scrimber Boards

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Effects of bamboo species, adhesives, and steam-heating treatment (SHT) were examined relative to mechanical properties and dimensional stability of oriented bamboo scrimber board (OBSB) made from makino bamboo (*Phyllostachys makinoi* Hayata) and moso bamboo (*P. pubescens* (Mazel)) strips. Results indicated that OBSB produced using makino bamboo culms bonded with water-soluble phenol formaldehyde resin (PF) had significantly higher ultrasonic wave velocity ($V_{u\ (//)}$), tap tone sound velocity ($V_{t\ (//)}$), dynamic modulus of elasticity ($DMOE_{u\ (//)}$), and $DMOE_{t\ (//)}$ than that produced using moso bamboo bonded with water-soluble urea formaldehyde resin (UF) ($p < 0.05$). The two types of OBSB showed the same trend of $DMOE_u > DMOE_t >$ modulus of elasticity (MOE). In addition, OBSB made using steam-heated makino bamboo and PF had the largest modulus of rupture (MOR) (210.5 MPa), exceeding that of OBSB made using laminated bamboo timber and wood-plastic composite (WPC). However, OBSB made using steam-heated moso bamboo and UF exhibited the highest screw holding strength (SHS). Improvement in dimensional stability was observed in OBSB manufactured using steam-heated culms. Finally, OBSB glued with UF had lower water absorption, thickness swelling, and volumetric swelling than that glued with PF.

Keywords: Bamboo culms; Phenol formaldehyde resin; Urea formaldehyde resin; Oriented bamboo scrimber board; Mechanical property; Dimensional stability

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INTRODUCTION

Bamboo has high carbon fixation efficiency, a short renewal cycle, and good mechanical strength properties. In the past two decades, many countries have developed methods for applying bamboo as structural materials in engineering and construction (Obata *et al*. 2006; Abdul Khalil *et al*. 2012; Sharma *et al*. 2015a). However, owing to increasing demand for diverse applications of bamboo, problems with mass production of bamboo materials have arisen. Laminated bamboo and bamboo particleboards have been widely used in furniture making, flooring, and interior decoration (Lee *et al*. 1998; Nugroho and Ando 2001; Obata *et al*. 2001; Lee and Liu 2003; Okubo *et al*. 2004; Sulastiningsih and Nurwati 2009; Verma and Chariar 2012; Lee *et al*. 2012). However, their processing causes defects in strength properties and incurs high costs, thus limiting their utilization. In view of these disadvantages, bamboo research scholars developed oriented bamboo scrimber board (OBSB), which has an ideal surface texture, high hardness, and good longitudinal compressive strength (Wang 1989; Yu and Yu 2013; Yu *et al*. 2015; Sharma *et al*. 2015a,b), suited for indoor and outdoor flooring, railings, furniture making, and structural engineering.

At present, only Chung and Wang (2017) have evaluated the strength properties of different OBSBs made of moso bamboo (*Phyllostachys pubescens*) from China and Taiwan. Their results showed that OBSB made using moso bamboo from Taiwan at a density of 1.0 g/cm^3 had higher modulus of elasticity (MOE), modulus of rupture (MOR), and internal bonding strength (IB) than OBSB made using moso bamboo from China. Chung and Wang (2018) also evaluated the effects of epidermis-peeling treatment (EPT) and steam-heating treatment (SHT) on OBSB made from makino (*P. makinoi*) and moso bamboo. Their findings revealed that OBSB made from regular makino bamboo and moso bamboo originating from Taiwan had higher MOE, MOR, and screw holding strength (SHS), indicating higher mechanical strength. In the production of wood composites, adhesives are required for bonding. Past studies have reported variations in strength, dimensional stability, and durability of wood composites due to differences in gluing properties of the adhesives used (Liu 1984; Pizzi 1993; Uysal 2005; Bal and Bektaş 2012). Therefore, choosing the appropriate adhesive is important when developing wood composites. Phenol formaldehyde resin (PF) and urea formaldehyde resin (UF) are the two most widely used adhesives for producing furniture and wood composites (Liu *et al*. 1993). Prior to this study, there has been no research on effects of PF and UF used as adhesives on the physical strength, mechanical strength, and dimensional stability of OBSB.

In this study, OBSBs of 1.0 g/cm^3 density were made using treated and non-heat-treated moso bamboo and makino bamboo culms from Taiwan and glued with PF and UF. Their mechanical properties and dimensional stability were evaluated using non-destructive testing. Findings from this study will provide the bamboo processing industry a better understanding of the appropriate bamboo species, pre-treatment, and adhesives for making engineered wood with good mechanical properties and dimensional stability.

EXPERIMENTAL

Materials

Three-year-old moso bamboo (*Phyllostachys pubescens* (Mazel)) and makino bamboo (*Phyllostachys makinoi* Hayata) culms were collected from the Experimental Forest of National Taiwan University in Shuili Township, Nantou County, Taiwan, in October 2015. Figure 1 illustrates the manufacturing of OBSB specimens. First, all bamboo culms were cut into 2-cm-wide strips and then pre-treated with an alkaline solution containing 2% potassium hydroxide (KOH) at 100 °C for 30 min. The strips were then oven-dried at 80 °C. For SHT, bamboo strips were placed in a steam-heating furnace at 120 °C for 6 h, followed by air-drying. The 2-cm-wide strips were further extruded into thin strips of 450 mm × 1.0 to 2.0 mm (length × width) by mechanical processing. The thin strips were dried at 80 °C for 12 h to reach a constant weight (moisture content of about 8%) and then placed unidirectionally in an iron frame of 450 mm × 450 mm × 12 mm (length × width × thickness).

Board density of 1.0 g/cm^3 and bonding agent at 10 wt% of raw material were adopted according to the Chinese National Standards (CNS) 2215 specifications for weight of bamboo strips and quantity of adhesive used, respectively for the test on particleboards. Two adhesives were used in this study: water-based UF with a solids content of 63.6% and alcohol-based PF with a solids content of 58.1% (Wood Glue Industrial Co., Ltd., Tainan, Taiwan). The strips were hot-pressed (STH No. 4; China Hydraulic Industry Co., Ltd., Taipei County, Taiwan) at curing temperatures of 120 °C and 145 °C at 150 kgf/cm^2 for 12 min followed by 10-min cooling. Prior to the experiments, all specimens were conditioned in a controlled environment at 20 °C and a relative humidity (RH) of 65% for 2 weeks. Table 1 summarizes the treatment conditions and codes for the eight experimental OBSB groups (n = 9).

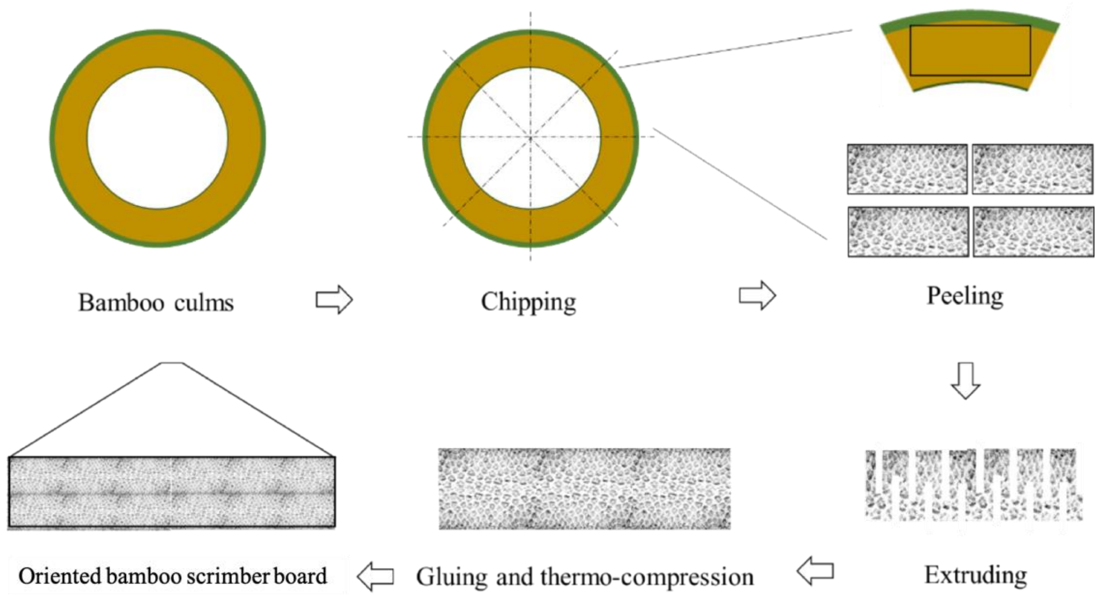

Fig. 1. Manufacturing process of OBSB

Table 1. Experimental OBSB Groups and their Codes

No.	Species	Heat Treatment	Adhesives	Code
1	Makino bamboo	Yes	UF	Pm-H-U
2			PF	Pm-H-P
3		No	UF	Pm-U
4			PF	Pm-P
5	Moso bamboo	Yes	UF	Moso-H-U
6			PF	Moso-H-P
7		No	UF	Moso-U
8			PF	Moso-P

Methods

Density

According to CNS 451 (2013), after the OBSB specimens were conditioned at 20 °C and RH of 65% for 4 weeks, the dry weight and volume were measured, and the density was calculated.

Moisture content

According to CNS 452 (2005), OBSB cubes of 3 cm^3 in size were oven-dried at 100 °C to 105 °C to constant weight. The difference in weight before and after drying indicates the moisture content (MC%) in the specimens.

Non-destructive evaluation

Non-destructive testing (NDT) was conducted to evaluate the ultrasonic-wave velocity (V_u) and dynamic modulus of elasticity ($DMOE_u$) using an ultrasonic analyzer (Sylvatest Duo; CBS & CBT, Saint-Sulpice, Switzerland) at a frequency of 22 kHz. The OBSB specimens of size 240 mm × 50 mm × 12 mm (length × width × thickness) were placed between the transmitting and receiving transducers, and the transmission time of the ultrasonic wave (travel time) was recorded.

Another NDT was performed to evaluate the tap tone sound velocity (V_t) and dynamic modulus of elasticity ($DMOE_t$) using a tap tone NDT device (Multi-purpose FFT analyzer CF-5220; Ono Sokki Co., Ltd., Yokohama, Japan). Each OBSB specimen of size 240 mm × 50 mm × 12 mm (length × width × thickness) was supported at the center by a piece of foam and struck on one end with a hard-rubber hammer. The tap tone was transmitted from the end hit with the hammer and received by the microphone placed at the other end. The instantaneously generated sound waveform was decomposed into a spectrum using the Fast Fourier Transform (FFT) (CF- 360Z; Ono Sokki Co., Yokohama, Japan) to measure the natural vibration frequency.

Mechanical strength analysis

The mechanical strength of OBSB specimens was examined according to the ASTM D1037 (2006) standard. The static bending test was performed using a universal-type testing machine (UH-10A; Shimadzu, Tokyo, Japan) according to the center-loading method for specimens. A concentrated bending load was applied at the center with a span 15 times the thickness of the specimen. Both MOE and MOR were calculated from the load-deflection curves.

Nail withdrawal resistance analysis

According to CNS 2215 (2012), OBSB specimens were placed in a controlled environment with RH of 65% for 3 weeks. The dimensions of each OBSB specimen were 100 mm × 50.0 mm × 12.0 mm (length × width × thickness), and those of the wood screws were 2.7 mm × 16.0 mm (diameter × length). Wood screws were drilled vertically into OBSB specimens to a depth of 11.0 mm and then pulled up vertically at a rate of 2.0 mm/min. The maximum pull loading was measured, and the average of three measurements was recorded as the nail withdrawal resistance.

Dimensional stability

According to ASTM D1037 (2006), all OBSB specimens were placed parallel to each other at a depth of 30 mm under water and soaked for 2 h and 24 h, and their weight, thickness, and volume before and after soaking were measured. Differences in weight, thickness, and volume before and after soaking were calculated to determine water absorption (WA%), thickness swelling (TS%), and volumetric swelling (S%).

Statistical analysis

The statistical software SPSS (IBM Corp., v.20, Armonk, NY, USA) was used as a data analysis tool in this study. All multiple comparisons of physical and mechanical properties were subjected to Tukey's tests and analysis of variance (ANOVA) tests. Significant differences between the mean values of the control and experimental specimens were determined using the Duncan's multiple range test.

RESULTS AND DISCUSSION

Density and Moisture Content

Both density and MC% of wood and bamboo had significant effects on the strength, dimensional stability, and durability of composites made with these materials. Table 2 lists the density and MC% of the eight experimental OBSB groups. Regardless of bamboo species and adhesive used, and whether steam-heated or not, the observed differences among the values of the density of all OBSB specimens before and after the 4-week conditioning ranged between 0.02 and 0.05 g/cm^3, indicating insignificant difference ($p > 0.05$). These results reveal that bamboo species, adhesive used, and heat treatment had no effect on OBSB density.

Table 2. Oven-dried Density and Moisture Content of Eight Experimental OBSB Groups

Code	Density (g/cm^3)		MC (%)
	RH 65%	Oven-dried	RH 65%
Pm-H-U	1.05 (0.01)	1.03 (0.02)^{a}	7.47 (0.26) ^{a}
Pm-H-P	1.04 (0.03)	1.03 (0.04)^{a}	4.26 (0.14) ^{c}
Pm-U	0.99 (0.01)	0.97 (0.02)^{a}	7.88 (0.12) ^{ab}
Pm-P	1.02 (0.06)	1.00 (0.05)^{a}	5.23 (0.43)^{bc}
Moso-H-U	1.01 (0.05)	0.98 (0.05)^{a}	7.20 (0.13) ^{ab}
Moso-H-P	1.03 (0.02)	1.01 (0.02)^{a}	4.70 (0.23)^{bc}
Moso-U	1.05 (0.02)	1.03 (0.03)^{a}	6.74 (0.20) ^{b}
Moso-P	1.03 (0.02)	1.02 (0.02)^{a}	4.97 (0.43)^{bc}
Different letters indicate significant differences at the 0.05 level by ANOVA			

However, variations in MC% were observed in specimens made using different bamboo species and adhesives with and without heat treatment. As can be seen in Table 2, SHT reduced the MC% of Pm-U and Pm-P from 7.88% and 5.23% to 7.47% and 4.26%, respectively. In contrast, the changes in MC% after SHT were inconsistent for Moso-OBSB glued with different adhesives. Though SHT decreased the MC% of Moso-P from 4.97% to 4.70%, it increased the MC% of Moso-U from 6.74% to 7.20%. A decrease in MC% after SHT was also observed by Hakkou *et al.* (2005) when they assessed the effect of SHT on the wettability and mass loss of wood. The present findings also revealed lower MC% in PF-glued OBSBs than in their UF-glued counterparts, which echo the results reported by Huang and Lin (1983). In their study on particleboards manufactured using UF, PF, and melamine formaldehyde resin (MF), water absorption and thickness of the board surface for different adhesives were in the order of MF < PF < UF. Good permeability and gluing properties between PF and makino bamboo contribute to low MC%, which indirectly improves dimensional stability.

Ultrasonic-wave Velocity and Dynamic Modulus of Elasticity

Table 3 shows the average V_u and $DMOE_u$ of the eight experimental OBSB groups. As shown, the $V_{u\,(//)}$ of Pm-OBSB (5020 m/s to 5780 m/s) was slightly higher than that of Moso-OBSB (4917 m/s to 5071 m/s). With the exception of UF-glued Pm-OBSB, SHT decreased $V_{u\,(//)}$, and Pm-OBSB specimens showed more significant reduction in $V_{u\,(//)}$, indicating that SHT had a stronger effect on Pm than on Moso. Whether heat-treated or not, PF-glued OBSB specimens had higher $V_{u\,(//)}$ than their UF-glued counterparts, but the differences were not statistically significant ($p > 0.05$).

The $DMOE_{u\,(//)}$ of Pm-OBSB (24.23 GPa to 34.39 GPa) was also slightly higher than that of Moso-OBSB (23.49 GPa to 24.81 GPa). However, contrasting trends were observed after SHT. For Pm-OBSB, SHT decreased the $DMOE_{u\,(//)}$ in PF-glued specimens but increased that in their UF-glued counterparts. For Moso-OBSB, SHT increased the $DMOE_{u\,(//)}$ in PF-glued specimens but decreased that in their UF-glued counterparts. Consequently, while Pm-P had greater $DMOE_{u\,(//)}$ than Pm-U, Pm-P had smaller $DMOE_{u\,(//)}$ than Pm-U following SHT. A similar reversal was observed for Moso-OBSB. Initially Moso-U had greater $DMOE_{u\,(//)}$ than Moso-P; after SHT, Moso-U had smaller $DMOE_{u\,(//)}$ than Moso-P. Changes in $DMOE_{u\,(//)}$ due to SHT, whether positive or negative, were larger in Pm-OBSB, again indicating that SHT had a more marked effect on Pm-OBSB than on Moso-OBSB ($p < 0.05$). Compared with the V_u (4016 m/s to 4174 m/s) and $DMOE_u$ (10.4 GPa to 11.4 GPa) obtained by Lee *et al*. (2012) for laminated board made with moso bamboo from China, higher V_u and $DMOE_u$ were observed for the OBSB specimens in this study. Such differences in V_u and $DMOE_u$ can be attributed to the higher board density of OBSB compared with bamboo laminated board. Hot pressing of bamboo after extrusion makes the bamboo structure denser. These results indicated the significant influence of density on V_u and $DMOE_u$.

Tap Tone Sound Velocity and Dynamic Modulus of Elasticity

Both tap tone sound velocity and $DMOE_t$ of the eight experimental OBSB groups showed slightly different trends compared with V_u and $DMOE_u$.

Table 3. $V_{u\,(//)}$, $V_{t\,(//)}$, $DMOE_{t\,(//)}$, and $DMOE_{u\,(//)}$ of Eight Experimental OBSB Groups

Code	V_u (m/s)	V_t (m/s)	$DMOE_u$ (GPa)	$DMOE_t$ (GPa)
Pm-H-U	5780 (57)^b	4547 (51)	34.39 (0.62)**	19.48 (0.94)
Pm-H-P	5071 (53)^b	4605 (58)	24.23 (0.97)**	19.99 (0.80)
Pm-U	5720 (49)^a	5164 (18)	31.61 (2.44)*	25.76 (1.80)
Pm-P	5738 (57)^a	5197 (52)	32.77 (0.74)*	27.48 (0.86)
Moso-H-U	4917 (50)^b	4523 (56)	23.49 (0.99)**	20.66 (0.94)
Moso-H-P	5030 (52)^b	4629 (42)	24.81 (0.53)**	21.54 (0.74)
Moso-U	5050 (57)^b	4547 (51)	24.23 (0.97)**	19.99 (0.80)
Moso-P	5071 (53)^b	4605 (58)	23.89 (0.62)**	19.48 (0.94)

Results are mean ± standard error (SE), n = 9; numbers followed by different letters (a through e) are statistically different at the probability level of $p < 0.05$ according to Tukey's test and ANOVA

As shown in Table 3, the $V_{t\,(//)}$ of Pm-OBSB (4547 m/s to 5197 m/s) was slightly higher than that of Moso-OBSB (4523 m/s to 4629 m/s). Except for PF-glued Moso-OBSB, SHT decreased $V_{t\,(//)}$, and Pm-OBSB showed a more notable reduction, echoing the above finding that SHT had a stronger effect on Pm-OBSB than Moso-OBSB. In addition, whether heat-treated or not, PF-glued OBSB specimens had higher $V_{t\,(//)}$ than their UF-glued counterparts, but the differences were not statistically significant ($p > 0.05$).

Similarly, the $DMOE_{t\,(//)}$ of Pm-OBSB (19.48 GPa to 27.48 GPa) was slightly higher than that of Moso-OBSB (19.48 m/s to 21.54 m/s). Regardless of the adhesive used, SHT decreased the $DMOE_{t\,(//)}$ of Pm-OBSB but increased the $DMOE_{t\,(//)}$ of Moso-OBSB, revealing that SHT had different effects on the two bamboo species. In addition, the reduction in $DMOE_{t\,(//)}$ for Pm-OBSB was more notable than the increase in $DMOE_{t\,(//)}$ for Moso-OBSB, again indicating that SHT had a greater impact on Pm-OBSB. With the exception of non-heat-treated Moso-OBSB, all PF-glued specimens had higher $DMOE_{t\,(//)}$ than their UF-glued counterparts, but the differences were not statistically significant ($p > 0.05$). In comparison, both V_u and $DMOE_u$ of all OBSB specimens were higher than their V_t and $DMOE_t$. This finding is consistent with the results obtained by Lee and Yang (2010) in their evaluation of China fir laminae using NDT. Wang *et al*. (2008) also reported DMOEu > DMOEt > MOE in their study on domestic Japanese cedar, Taiwan fir, Douglas fir, and South pine.

Mechanical Strength

Figure 2 shows the MOE and MOR of the eight experimental OBSB groups. The MOE values of heat-treated OBSB specimens were higher than that of their non-heat-treated counterparts. Whether heat-treated or not, Pm-OBSB had higher MOE than their Moso-OBSB counterparts; and PF-glued specimens, had higher MOE than their UF-glued counterparts, but the differences were not statistically significant. As pointed out by Halabe *et al*. (1997) and Tsai (1985), DMOE exceeding MOE may be due to the types of test used. To obtain MOE using a bending test, the specimens are placed under a constant load for a long duration, resulting in torsional deformation and increased deflection due to shear forces. In contrast, DMOE can be determined using NDT with no or only short-term impact on the specimen. The same trend was observed for the MOR of the experimental OBSB specimens. The MOR of heat-treated OBSB specimens were significantly higher than that of their non-heat-treated counterparts, regardless of bamboo species and adhesives used. Moreover, whether heat-treated or not, PF-glued specimens had higher MOR than their UF-glued counterparts.

In summary, better strength properties were observed for Pm-OBSB. The highest MOR of 210.50 MPa obtained for Pm-H-P far exceeded the peak MOR of 95.6 MPa for laminated board made with China-origin moso bamboo (Lee *et al*. 2012) and 35 MPa to 45 MPa for polyethylene-wood composites (Geng and Simonsen 2004). Moreover, both SHT and PF contributed to enhanced strength in OBSBs. This finding is consistent with the results obtained by Çolak *et al.* (2004) that pine laminated wood laminates (LVL) glued with PF had higher strength than those glued with UF; and agrees with observations reported by Huang and Lin (1983) that particleboards glued with PF had higher MOE and MOR than those glued with UF. In general, bonding strength is affected by many factors, such as mole ratio and gelation time of adhesives, hot-pressing conditions, pH value and wettability of bamboo strips. Reasons accounting for the difference in bonding strength between PF and UF merit further study.

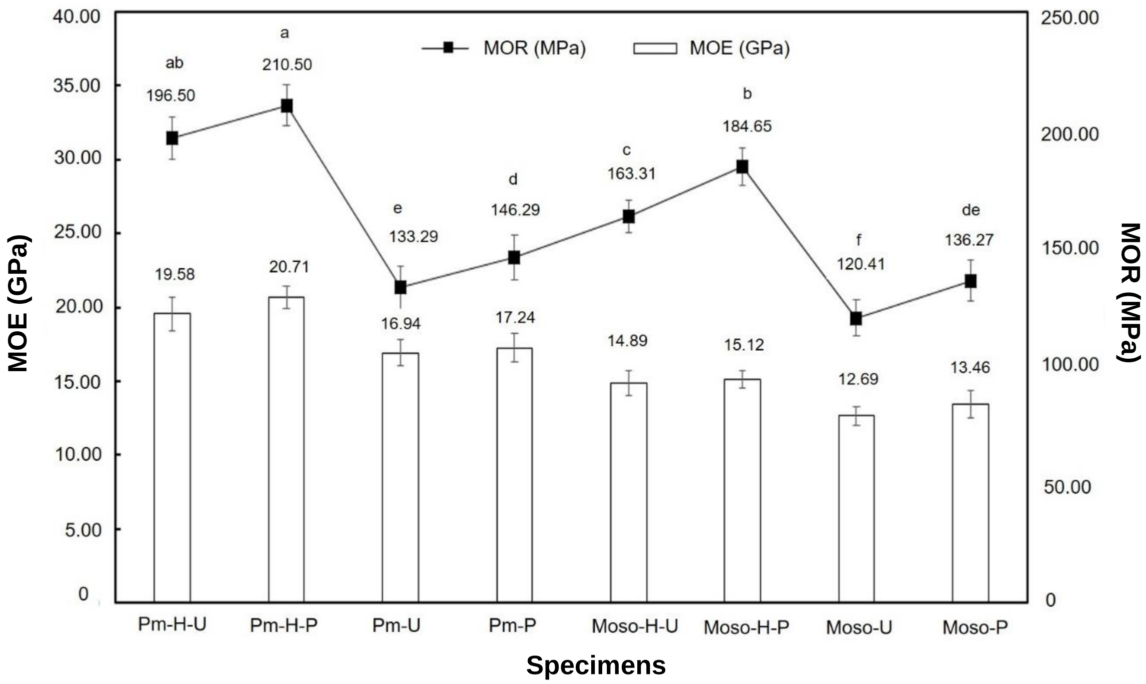

Fig. 2. MOE $_{(//)}$ and MOR $_{(//)}$ of eight experimental OBSB groups (results are mean ± SE, n = 9; numbers followed by different letters (a through e) are statistically different at a probability level of $p < 0.05$ according to Tukey's test and ANOVA)

Screw Holding Strength

Figure 3 shows the SHS of the experimental OBSB groups. As can be seen, Moso-OBSB specimens had higher SHS than their Pm-OBSB counterparts.

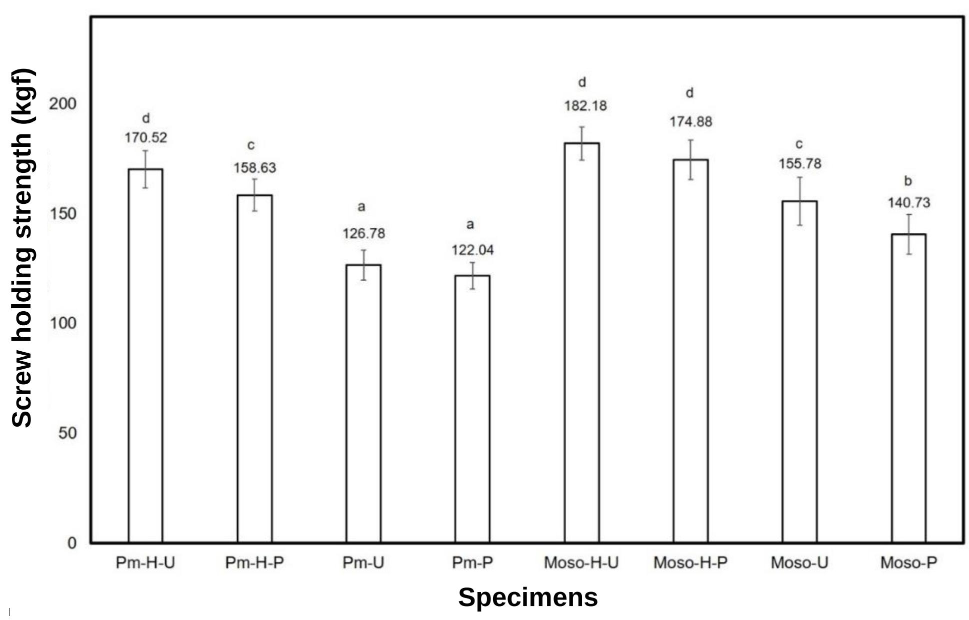

Fig. 3. Screw holding strength of eight experimental OBSB groups (results are mean ± SE, n = 9; numbers followed by different letters (a through e) are statistically different at a probability level of $p < 0.05$ according to Tukey's test and ANOVA)

Regardless of bamboo species, heat-treated specimens had higher SHS than their non-treated counterparts, suggesting that SHT contributes to enhanced SHS. Moreover, UF-glued specimens, whether heat-treated or not, had higher SHS than their PF-glued counterparts, showing that SHS was improved when using UF as adhesive. Moso-H-U had the highest SHS of 182.18 kgf, and Pm-P had the lowest SHS of 122.04 kgf. These results showed that optimal SHS was obtained using heat-treated moso bamboo glued with UF, which is related to increased internal bond strength (IB) (Kojima and Suzuki 2011). Lin and Huang (2001) also reported higher SHS for hot-pressed particleboards with higher densification, stronger cohesion, and better gluing quality.

Dimensional Stability

Table 4 displays the results for WA%, TS%, and S%, which are all indicators of dimensional stability. Higher WA% was observed in Moso-OBSB than in Pm-OBSB. Moreover, regardless of bamboo species, non-heat-treated specimens had higher WA% than their heated counterparts, indicating that SHT reduced water absorption. Furthermore, PF-glued specimens, whether heat-treated or not, had higher WA% than their UF-glued counterparts. Hence, the highest WA% (35.89%) was observed in Moso-P, while the lowest WA% (14.83%) was found in Pm-H-U. As shown in Table 4, OBSB made from non-heat-treated moso bamboo using PF as adhesive had higher TS% and S%. The highest TS% (16.96%) and S% (26.41%) were observed in Moso-P, while the lowest TS% (6.99%) and S% (10.48%) were observed in Moso-H-U. These findings indicated reduction in thickness and volume expansion after SHT. Moreover, Table 4 also revealed that PF-glued OBSB had higher WA%, TS% and S% than their UF-glued counterparts, indicating lower dimensional stability in PF-glued OBSB, which can be attributed to the lower permeability and wettability between bamboo strips and alcohol-based PF (molecular weight = 134.13 g/mol) compared with water-based UF (molecular weight = 90.08 g/mol).

Table 4. Thickness Swelling, Volumetric Swelling, and Water Absorption of Eight Experimental OBSB Groups

Code	WA%	TS%	S%
Pm-H-U	14.83 (1.51) ^{a}	7.77 (0.61)	11.77 (0.86)
Pm-H-P	15.71 (1.28) ^{a}	7.98 (0.84)	12.57 (1.18)
Pm-U	25.95 (2.14) ^{b}	12.98 (1.71)	20.37 (0.87)
Pm-P	26.28 (1.39) ^{b}	13.70 (1.26)	24.00 (1.13)
Moso-H-U	16.48 (1.26) ^{a}	06.99 (2.01)	10.48 (2.74)
Moso-H-P	24.54 (1.96) ^{b}	14.02 (1.24)	19.79 (2.29)
Moso-U	25.71 (0.97) ^{b}	11.94 (0.93)	20.66 (0.91)
Moso-P	35.89 (1.07) ^{c}	16.96 (1.05)	26.41 (1.49)

Results are mean ± SE, n = 9; numbers followed by different letters (a through e) are statistically different at the probability level of $p < 0.05$ according to Tukey's test and ANOVA.

Lee *et al.* (1996) examined both physical and mechanical properties of moso bamboo-made strand board and found that the amount of adhesives used affected the MOE, MOR, and IB, but not the spring-back rate, linear expansion, or nail withdrawal resistance. Yu *et al*. (2015) found that water absorption of OBSB influenced the board structure and bond strength of fibers, which undermined the dimensional stability, mechanical properties, and physical properties of the entire product. Mohebby and Llbeighi (2007) reported degradation of woody material in hemicellulose with good hygroscopic properties during heat treatment. Such treatment also caused the non-crystalline region in cellulose to degrade and increased the crystallinity of the fiber, which prevented moisture from entering the fiber. Previous analysis also showed decreased equilibrium moisture content in heat-treated bamboo. Therefore, heat treatment reduces the hygroscopicity of bamboo. This finding is consistent with the results reported by Huang *et al*. (1993) on the water absorption properties of moso bamboo after heat treatment with three different media.

CONCLUSIONS

1. The dry density of oriented bamboo scrimber board (OBSB) made with different bamboo species and adhesives was approximately 1.0 g/cm^3 with insignificant variation. In contrast, the percent moisture content (MC%) of OBSB decreased after SH. MC% was slightly lower in PF-glued OBSB than in UF-glued OBSB. PF-glued Pm-OBSB had significantly higher ultrasonic wave velocity ($V_{u\ (//)}$), tap tone sound velocity ($V_{t\ (//)}$), dynamic modulus of elasticity ($DMOE_{u\ (//)}$), and $DMOE_{t\ (//)}$ than UF-glued Moso OBSB ($p < 0.05$).
2. Regardless of bamboo species and adhesive used, and whether heat-treated or not, OBSBs had $DMOE_u > DMOE_t > MOE$. Mechanical strength of OBSB made from makino bamboo and glued with PF was larger than OBSB made from moso bamboo and glued with UF. Steam-heated Pm-OBSB glued with PF (Pm-H-P) showed the highest strength of 210.5 MPa, while steam-heated Moso-OBSB glued with UF (Moso-H-U) had the highest SHS.
3. Heat treatment reduced WA%, TS%, and S% of both Pm-OBSB and Moso-OBSB. Whether heat-treated or not, OBSB glued with UF had lower WA%, TS%, and S% than that glued with PF.

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