Decay Resistance of Bamboo Oriented Strand Board Pretreated with Copper-based Preservatives

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To enhance the decay resistance of bamboo oriented strand board (OSB) products, the strands were dipped in solutions of alkaline copper quat (ACQ) and copper azole (CA) and bonded with phenol formaldehyde resin into two types of OSB panels, *i.e.*, panels with 100% treated strands and those with treated strands only in the face layers. The results indicated that the decay resistance of treated panels was effectively enhanced. The physical and mechanical properties of all treated panels exceeded the requirements specified for category OSB/4 or OSB/3 in the standard LY/T 1580-2010. Statistical data analysis showed that pretreatment with ACQ and CA did not have detrimental effects on the overall physical and mechanical properties of panels at the loading levels investigated in this study. Panels with pretreated strands only in the face layers had strong decay resistance and comparable overall properties as those with 100% treated strands. The results suggest that pretreatment is a promising way to introduce waterborne ACQ and CA to protect bamboo OSB.

Keywords: Decay resistance; Bamboo oriented strand board; Alkaline copper quat; Copper azole; Phenol formaldehyde resin; Physical and mechanical properties

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INTRODUCTION

Oriented strand board (OSB) has experienced a spectacular increase in both production and consumption in North America since the 1990s because of its wide acceptance and application in construction and its utilization of non-peeler and non-sawn logs. Since the late 1970s, research on OSB has been conducted in China, and OSB mills have been built with domestic and imported equipment (Xu 2010). In 2010, the first large-scale OSB production line, with an annual capacity of 220,000 m^3, was established in the Hubei province. Since 2014, China's OSB industry has grown rapidly. Three Dieffenbacher continuous press system production lines, with a total annual capacity of 770,000 m^3, have been constructed in Hubei, Shandong, and Guizhou provinces (Anonymous 2014a). Another line in the Jiangsu province has also been constructed, and it is reported to have a capacity of 200,000 m^3, focusing on OSB for packing and container flooring (Anonymous 2014b).

With the decrease in quality and quantity of wood resources worldwide, many attempts have been made to produce OSB from natural renewable fibers other than wood

(Wasylciw and Wang 2001; Han *et al.* 2005; Febrianto *et al.* 2012). Among others, bamboo has been considered to be a potential raw material for OSB (Lee *et al.* 1996; Fu 2007), as it is fast-growing (3 to 5 years), high-yield, and renewable, presenting high density and strength, toughness, and hardness comparable with some hardwood species (Zhang 1995; Lee *et al.* 1996). China is rich in bamboo, and there are 39 genera and more than 500 species of bamboo. At the end of 2011, China had 6.73 million ha of bamboo forest land with an output of bamboo accounting for 1/3 of the world total (SFA 2013). Many research and development projects have been carried out to make OSB from bamboo (Yin 1987; Fu 2007; Zhang *et al.* 2007). In the industry, Yunnan Yung Lifa Forest Co. Ltd. has built pilot lines and produced bamboo OSB for container flooring board (Anonymous 2012). All these efforts demonstrate that bamboo is a promising raw material for OSB in China, which is deficient in forestry but rich in bamboo resources and has a huge demand for wood panel products. However, bamboo contains higher levels of nutrients for fungi compared with most wood species, including 2.02% to 5.18% starch, 2% sugar, 2.18% to 3.55% fat and wax, and 1.5% to 6.0% protein contents (Zhang 1995). Therefore, bamboo and bamboo products are more prone to biological deterioration. Thus, preservative treatment is essential to improve the durability of bamboo-based products and to expand their end uses.

Protection of OSB and waferboard from biological deterioration with boric acid and inorganic borates such as zinc borate (ZB), calcium borate, and sodium borate has been extensively investigated *via* in-process treatment (Laks and Manning 1994; Sean *et al.* 1999; Laks *et al.* 2000; Lee 2003; Zhou 2004). Among them, ZB has been registered with the US Environmental Protection Agency and by far has been the most commonly used in-process preservative (Laks *et al.* 2000). One main disadvantage of borates is their tendency to reduce the flowability of phenol formaldehyde (PF) resin, which has adverse effects on the properties of treated panels, especially at high borate loading levels (Sean *et al.* 1999; Kirkpatrick and Barnes 2006). Moreover, ZB and other borates are generally used for interior applications (Kirkpatrick and Barnes 2006; Lorenz and Frihart 2006). Another type of preservative that has been extensively used for wood protection and drawing more interest is copper-based preservative (Freeman and McIntyre 2008). Chromium and arsenic-free copper-based preservatives, *e.g.*, alkaline copper quat (ACQ) and copper azole (CA), have been widely used as substitutes for chromated copper arsenate for wood preservation (Yang *et al.* 2012) and have been investigated as protection for adhesive-bonded wood products. For example, both ACQ and CA were applied to protect wood-based composites *via* a vacuum-impregnation post-treatment (Tascigolu and Tsunoda 2010a,b). The bonding performance of phenol-resorcinol-formaldehyde (PRF) adhesive with ACQ- and CA-treated wood was evaluated by Lorenz and Frihart (2006). Three ACQ-pretreated hardwood lumbers were bonded with resorcinol resin adhesive, and the mechanical properties of treated glulam were examined (Yang *et al.* 2012); also, the effects of CA and ACQ on the properties of southern pine laminated veneer lumber (LVL) have been determined (Shukla and Kamdem 2012).

Because the solutions of waterborne ACQ and CA preservatives are normally low in concentration, an in-process treatment, which generally incorporates preservatives with dry wood elements before mat forming and hot-pressing, may result in very high mat moisture content, which in turn brings up challenges and difficulties for hot-pressing. Post-treatment with these preservatives often involves pressure impregnation and a subsequent drying process that causes excessive thickness swelling and thus has possible detrimental effects on both the structure and properties of OSB and other non-veneer wood composites (Tascioglu and Tsunoda 2010a, b; Taşçioğlu 2013). In contrast, with pretreatment, *i.e.*, dipping or impregnating strands in dilute preservative solution, the treated strands can then be dried and used subsequently for OSB manufacturing. Therefore, a product containing preservatives with the desired physical and mechanical properties can be realized in a conventional way if an appropriate combination of adhesive and preservatives is selected. However, little research has been reported regarding the protection of bamboo OSB with copper-based preservatives *via* strand pretreatment. The purposes of this study were to evaluate the feasibility of enhancing the decay resistance of bamboo OSB with ACQ and CA *via* pretreatment and to determine the effects of this treatment on the properties of bamboo OSB panels. In addition, the possibility of protecting OSB panels with treated strands in face layers only was explored as well.

EXPERIMENTAL

Strand Preparation and Panel Fabrication

Four-year old moso bamboo (*Phyllostachys pubescens*) culms were collected from a bamboo forest in the Anhui province. Straight and clear bamboo culms were selected for the experiment. After removing a section approximately 20 cm long from the bottom, each culm was cross-cut into three round segments with lengths of 2.5 m. The segments were divided equally along the circumference into 2-cm-wide raw strips. After planing away the outer layer (cortex or bamboo green) and inner layer (pith or bamboo yellow), each raw strip was processed along the thickness into 10 to 14 thin strips. The air-dried thin strips were then bundled up and cross-cut into strands with a circular saw. The average strand length, width, and thickness were 67.4, 17.0, and 0.67 mm, respectively.

ACQ-3 and CA-2 preservatives (GB/T 27654 (2011)) were provided by the International Centre for Bamboo and Rattan. In the standard LY/T 1636 (2005), the minimum retention levels for C2 category (indoor, above ground) and C3 (outdoor, above ground) are 1.7 and 4.0 kg/m^3 for CA and ACQ, respectively. Because highly alkaline phenol formaldehyde (PF) resin probably inhibits fungal growth (Laks *et al.* 2000) and thus helps to improve the decay resistance of PF-bonded bamboo OSB, a retention level lower than that for lumber may be sufficient for protecting OSB. On the other hand, the active components of some preservatives may be reduced during the OSB manufacturing process (Laks *et al.* 2000); therefore, a loading level higher than that for lumber would be needed to fully protect OSB panels preserved *via* pretreatment. To determine the appropriate loading levels, three nominal levels were tested for each preservative, *i.e.*, 3.0, 4.0, and 5.0 kg/m^3 for ACQ and 1.2, 1.7, and 2.2 kg/m^3 for CA. Pretreatment consisted of fully submerging air-dried bamboo strands for 1 min in diluted preservative solutions. The concentration of each solution corresponding to a specific loading level (*e.g.*, 4.0 kg/m^3 for ACQ) was pre-determined based on the average mass uptake of strands after preservative immersion (draining the excess liquid). All treated and control strands were dried at 80 °C to a moisture content of 3% to 5% before being used in the manufacture of OSB.

The PF resin was synthesized in the laboratory with 47% non-volatile solids and a pH of 11.0 to 12.0 and blended to strands at a resin content of 6%. A commercial emulsion wax with 30% non-volatile solids was used at the loading level of 1%. Both resin and wax were sprayed on the strands while they were tumbling in a lab drum blender. Resinated strands were then hand-formed into three-layered mats of 450 mm × 450 mm, with strands on face layers parallel and core strands randomly oriented. The ratio of face to core layers was 30:40:30. Because biodeterioration usually starts from the surface of a material, treated face layers may form a barrier strong enough to prohibit fungus hyphae from penetrating into the inner layers and thus protect OSB. It is therefore possible to obtain comparable decay resistance by treating face layers only instead of the whole panel. This may present two advantages: cost-effectiveness because less strands need to be treated with preservatives, and possible better bonding strength in the core if the preservative treatment affects the bonding quality. Consequently, two types of panels were made for the investigation, namely, panels with 100% treated strands (all strands treated -type A) and panels with 60% of the strands treated only (face strands treated only -type F). All mats were hot-pressed for 400 s at a platen temperature of 180 °C to the target thickness of 10 mm and a nominal density of 800 kg/m^3. Three replicates per treatment (plus control) were made for a total of 39 panels.

Evaluation of Properties and Performance

Physical and mechanical properties

The physical and mechanical properties were evaluated according to the standard LY/T 1580 (2010), which is essentially equivalent to EN 300 (2006) in terms of OSB classifications and specifications. For each of three replicates per treatment, four specimens measuring 250 mm × 50 mm × 10 mm were prepared for bending tests along and across the panel length (two for each direction), and six specimens of 50 mm × 50 mm × 10 mm were cut to determine internal bond strength (IB) and 24-h water soaking thickness swelling (TS_{24h}). The bending and internal bond strength tests were conducted using a microcomputer controlled electronic universal testing machine (Model CMT6104, Shenzhen Sans Testing Machine Co. Ltd., Shenzhen, China).

Decay resistance

A laboratory decay resistance test was conducted according to the standard GB/T 13942.1 (2009) on specimens of 20 mm × 20 mm × 10 mm. Potato dextrose agar culture was used as the medium for growing fungi during the test. To avoid excessive thickness swelling of the specimens, which may result in damage to their structure, specimens were oven-dried at 105 °C for 5 h instead of steam sterilization before inoculating decay fungi. For each treatment and control groups, two sets, each containing six specimens, were prepared for white-rot and brown-rot fungi decay tests. In addition, specimens of Chinese white poplar (*Populus tomentosa*) wood were prepared as a reference material to determine the viability of two fungi, *i.e.*, a brown-rot fungus *Gloeophyllum trabeum (G. trabeum*) and a white-rot fungus *Coriolus versicolor (C. versicolor*). All specimens were inspected for fungi growth after 120 days of incubation at a temperature of 28 °C and relative humidity of 75% to 85%. Their mass losses were determined based on the oven dry mass before and after the test.

Measurement of Retention Levels

The retention levels of preservatives in the panels were determined based on the method specified in the standard GB/T 23229 (2009) with flame atomic absorption spectrophotometer (AAS, Model TAS-990F, Beijing Purkinje General Instrument Co. Ltd, Beijing, China). Copper sulfate pentahydrate (analytical grade) was dissolved in distilled water to prepare five standard concentrations (1.0, 2.5, 5.0, 7.5, and 10.0 mg/L), and the absorbance at each concentration was used to establish a standard or calibration curve. To ensure a representative sampling, small pieces of treated bamboo OSB panels from three replicates of each treatment were first mixed together and then ground into powder passing a 30-mesh standard sieve. The powder was then dried at 70 °C for 2 h and another 0.5 to 1.0 h at 105 °C. Then, 0.5 g of dried powder was put into a 250-mL triangular flask, followed by the addition of 30-mL of distilled water and 5.0 g of sulfuric acid (analytical grade, 98% concentration). The flask was heated at 75 °C for 30 min and then cooled down to room temperature. The contents of the flask were transferred to a 200-mL volumetric flask, the volume was brought to 200 mL with distilled water, and the mixture was then filtered. The collected solution was analyzed with AAS. Copper content was determined using the standard curve and converted to retention levels of ACQ and CA. Only type A panels were analyzed.

Data Analysis

The generalized linear model (GLM) procedure was used to conduct the analysis of variance, and multiple comparisons with Tukey's Honestly Studentized Range (HSD) test was employed to determine whether the difference was significant between the means of board properties at the significance level of $\alpha = 0.05$. The data analysis was performed using SAS software (SAS® Proprietary Software 9.2, SAS Institute Inc., Cary, NC, USA).

RESULTS AND DISCUSSION

Measured Retention Levels

Table 1 shows the measured retention levels and the target loading levels of preservatives in type A bamboo OSB panels. The measured retention levels deviated from the designed values to some extent. The retention levels in ACQ-treated panels were slightly lower than the target values, whereas those in the panels with CA-treated strands were a little higher than the targets. However, the intervals between levels for each preservative treatment were large enough to determine their effects on the properties of panels. In practice, the difference between the actual and target values will be minimized by improving the pre-treatment procedures.

Table 1. Levels of Preservatives in Treated OSB Panels

Panel	Level (kg/m^3)	
	Target	Measured
ACQ-treated type A panels	3.0	2.84
	4.0	3.42
	5.0	4.67
CA-treated type A panels	1.2	1.52
	1.7	1.82
	2.2	2.32

Decay Resistance

Figures 1 and 2 display the average mass losses of specimens after exposure to two fungi for 120 days and statistical data analysis results from the HSD test. The mass losses of the reference material (Chinese white polar) against *C. versicolor* and *G. trabeum* were 51.8% and 53.7%, respectively, which were higher than the minimum mass loss of 45% to validate the viability of fungi as required by the standard GB/T 13942.1 (2009). The control OSB exhibited the lowest decay resistance among OSB samples, with a mass loss value of 9.6% against *C. versicolor* and 12.2% against *G. trabeum*. These mass losses were much lower than those of the reference material, probably because of the highly alkaline PF used at relatively high resin content (6%) and higher panel density (800 kg/m^3). All the treated panels had mass loss values less than 10%, and most of them had significantly lower mass losses than the control. Furthermore, the mass loss values tended to decrease with increasing preservative loading level. This demonstrated that the pretreatment improved the decay resistance of bamboo OSB panels, especially at high loading levels.

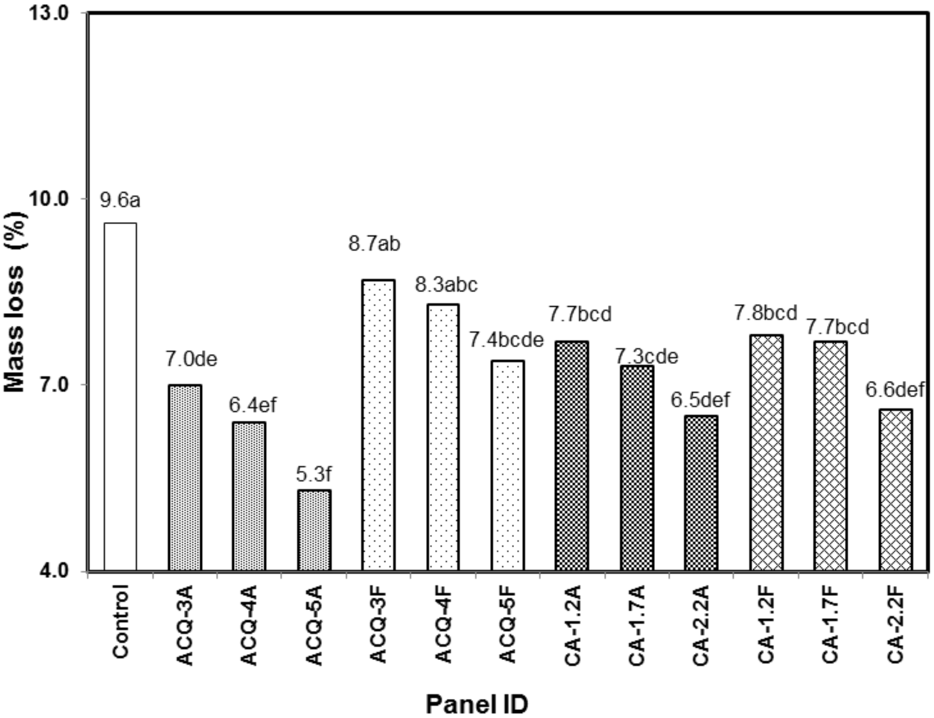

Fig. 1. Mean mass losses of bamboo OSB panels against *C. versicolor*.

(Note: Mean mass losses marked with the same letter(s) are not significantly different by HSD test at α = 0.05；Numbers in panel ID (also given in details in table 2) following the preservative names (ACQ and CA) represent their target levels (kg/m^3), while letters A and F correspond to panels either with all-treated strands or face-treated strands only.

Decay Resistance Against C. versicolor

In general, the mass loss caused by *C. versicolor* was significantly higher for the control than for the treated panels except ACQ-treated type F panels at loading levels of 3.0 and 4.0 kg/m^3 (Fig. 1). For ACQ-treated type A panels, the mass loss decreased slightly, from 7.0% to 6.4%, when the loading level was increased from 3.0 to 4.0 kg/m^3, while the loading level of 5.0 kg/m^3 resulted in a mass loss of 5.3%, which was a significant improvement of the decay resistance against *C. versicolor*. The mass loss of CA-treated type A panels followed the same trend, *i.e.*, the highest loading level (2.2

kg/m^3) produced the greatest decrease in mass loss, though the differences between three levels were not statistically significant. All type F panels presented better decay resistance compared with the control but had higher mass losses than type A panels at the same loading level. This suggests that there were differences in the decay resistance resulting from the total amounts of preservatives, which was especially true for ACQ treatment. All ACQ-treated type A panels presented a significantly lower mass loss than type F at levels of 3.0 and 4.0 kg/m^3, but type F panel with the highest loading level (5.0 kg/m^3) presented decay resistance comparable to type A panel with the lowest loading level (3.0 kg/m^3). Because the total amounts of ACQ in those two panels were the same, this implied that the efficacy of ACQ against *C. versicolor* depended rather on its overall level than on its distribution in different layers. The mass losses of CA-treated type A panels were only slightly lower than type F panels at the same levels, and the differences among them were not statistically significant.

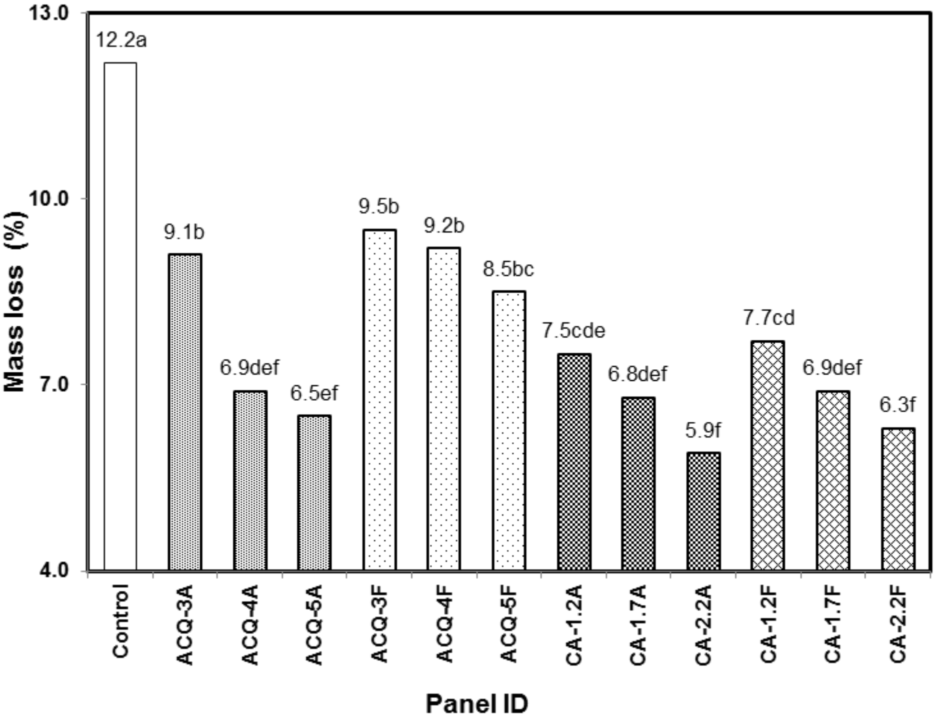

Fig. 2. Mean mass losses of bamboo OSB panels against *G. trabeum*

(Notes are the same for Fig. 1)

Decay Resistance Against G. trabeum

Similar to the case against *C. versicolor*, all the treated panels had significantly lower mass losses against *G. trabeum* than the control, and type F generally had higher mass losses than type A panels at the same loading level for each preservative (Fig. 2). The mass losses against *G. trabeum* of all the panels tended to decrease with increasing preservative loading levels. For ACQ treatment, the mass loss of type A panels treated with 3.0 kg/m^3 was significantly greater than those treated with the two higher levels (*i.e.*, 4.0 and 5.0 kg/m^3), but there was no significant difference between those two treatments. In the case of CA-treated type A panels, panels with 2.2 kg/m^3 CA did present a significantly higher efficacy against *G. trabeum* than those with 1.2 kg/m^3 CA, while the difference between levels of 1.2 and 1.7 kg/m^3 was not statistically significant. At the loading level of 3.0 kg/m^3, there was no significant difference between ACQ type A and F panels, whereas at the higher loading levels (4.0 and 5.0 kg/m^3), type A panels had significantly lower mass losses than type F panels. Both types of CA-treated panels presented significantly higher efficacy against *G. trabeum* at the highest level (2.2 kg/m^3), and the difference in mass losses between two types of panels at the same loading levels were not statistically significant. This implies that the treatment of face layers with CA was as efficient as the treatment of 100% strands in terms of decay resistance against *G. trabeum*. As far as the efficacy of the two preservatives was concerned, CA-treated panels showed consistently lower mass losses against *G. trabeum* than ACQ treated panels at corresponding levels. For example, the type A panel containing 1.2 kg/m^3 CA significantly outperformed type A panel treated with 3.0 kg/m^3 ACQ. Nevertheless, the mass losses of type A panels were statistically equivalent at higher levels of both preservatives. In the case of type F panels, CA treatment always had significantly better efficacy than ACQ treatment.

Physical and Mechanical Properties

Table 2 summarizes the physical and mechanical properties of the bamboo OSB panels, along with the statistical results from the HSD test. All the panels had excellent mechanical properties and extremely low thickness swelling after 24-h water soaking, which all met the requirements for category OSB/3 or OSB/4 specified in the standard LY/T 1580 (2010).

Table 2. Physical and Mechanical Properties of OSB Panels

Material	Level (kg/m^3)	Panel ID	MOE** (MPa)		MOR** (MPa)		IB** (MPa)	TS$_{24h}$** (%)
			∥	⊥	∥	⊥		
Control OSB	-	Control	6243 e***	1792 a	62.6 a	16.9 ab	1.81 a	2.6 d
ACQ-treated type A panels	3.0	ACQ-3A	9215 ab	2257 a	91.9 a	16.9 ab	1.92 a	2.4d
	4.0	ACQ-4A	8269 abcd	1542 a	67.4 a	15.7 ab	0.88 a	3.0 dc
	5.0	ACQ-5A	6636 de	1664 a	73.5 a	15.0 ab	1.70 a	3.4 bdc
ACQ-treated type F panels	3.0	ACQ-3F	6985 cde	1607 a	76.4 a	21.4 ab	1.25 a	3.9 abcd
	4.0	ACQ-4F	7590 bcde	1645 a	78.2 a	13.8 b	1.54 a	4.0 abcd
	5.0	ACQ-5F	5960 e	1876 a	64.2 a	24.1 a	1.65 a	3.4 bdc
CA-treated type A panels	1.2	CA-1.2A	8966 abc	1946 a	96.0 a	20.7 ab	1.35 a	3.1 bdc
	1.7	CA-1.7A	9138 ab	2331 a	68.8 a	20.6 ab	1.97 a	3.7 abcd
	2.2	CA-2.2A	8886 abc	2015 a	97.9 a	19.5 ab	1.65 a	2.6 d
CA-treated type F panels	1.2	CA-1.2F	9668 a	2269 a	92.1 a	19.8 ab	1.64 a	4.7 ab
	1.7	CA-1.7F	8964 abc	2300 a	71.4 a	19.4 ab	1.37 a	5.3 a
	2.2	CA-2.2F	10260 a	2179 a	85.8 a	20.1 ab	1.37 a	4.5 abc
OSB/3 *			3500	1400	22	11	0.34	15.0
OSB/4 *			4800	1900	30	16	0.50	12.0

* Categories specified in LY/T 1580 (2010).
** MOE, MOR, IB and TS stand for modulus of elasticity, modulus of rupture, internal bond strength and thickness swelling.
*** Means with the same letter(s) are not statistically different at α = 0.05 according to the HSD test.

Static bending properties

The modulus of elasticity parallel to the face orientation (MOE$_{//}$) of all panels exceeded the minimum requirement of 4800 MPa specified for OSB/4 (Table 2). The type F panel with 5.0 kg/m^3 ACQ had the lowest MOE$_{//}$ of 5960 MPa, while the type F panel with 2.2 kg/m^3 CA had the highest MOE$_{//}$ of 10260 MPa. All the treated panels had MOE$_{//}$ comparable to or higher than the control, except for the type F panel at 5.0 kg/m^3 ACQ, which was slightly inferior but not significantly lower than that of the control (6243 MPa). A clear downward trend in MOE$_{//}$ corresponding to the increase in loading level was only observed within the ACQ-treated type A group, and no correlation was found between loading level and the MOE$_{//}$ for other groups. Among all ACQ-treated panels, the type A panel with 3.0 kg/m^3 ACQ and the type F panel with 5.0 kg/m^3 ACQ had better MOE$_{\perp}$ values than the control, but the means of all panels were statistically the same. All CA-treated panels and the type A panel containing 3.0 kg/m^3 ACQ exceeded the minimum MOE$_{\perp}$ requirement of 1900 MPa for OSB/4, whereas the rest of the panels, including the control, were only qualified as OSB/3. As for the effects of preservative type, CA-treated panels generally had higher MOE in both directions than ACQ-treated panels and the control. However, for both preservatives, no definite correlation was found between the MOE and the loading level or panel type (A or F).

The modulus of rupture parallel to the face orientation (MOR$_{//}$) ranged from 62.6 MPa to 97.9 MPa and that perpendicular to the face orientation (MOR$_{\perp}$) fell within 13.8 MPa to 24.1 MPa (Table 2). MOR$_{//}$ values of all panels were much higher than the minimum requirement of 30 MPa for OSB/4. Although all treated panels had higher MOR$_{//}$ than the control, no significant differences in MOR$_{//}$ were found among them. As for the MOR$_{\perp}$, the type A panel treated with ACQ at levels of 4.0 and 5.0 kg/m^3 and the type F panel with the face layer containing 4.0 kg/m^3 ACQ met the requirements of MOR$_{\perp}$ for OSB/3 ($\geq$11 MPa), while the rest of the panels had a MOR$_{\perp}$ superior to the minimum requirements for OSB/4 (16 MPa). The type F panel with 4.0 kg/m^3 ACQ presented the lowest MOR$_{\perp}$ and was significantly lower than the type F panel with 5.0 kg/m^3 ACQ; the rest of the panels had comparable MOR$_{\perp}$. Similarly, CA treatment generally had higher average MOR than ACQ treatment. No definite correlations were observed either between MOR and loading level or between MOR and panel type. These results suggest that pre-treatment with both preservatives had no or little adverse effects on the MOR$_{//}$ and MOR$_{\perp}$.

Internal bond strength (IB)

All the panels had excellent IB values that surpassed the minimum requirement of 0.50 MPa for category OSB/4 (Table 2). The type A panel containing 4.0 kg/m^3 ACQ had the lowest IB (0.88 MPa), while the type A panel containing 1.7 kg/m^3 CA presented the best IB strength (1.97 MPa). Although the IB of the control was lower than that of type A panels containing 3.0 kg/m^3 ACQ and that containing 1.7 kg/m^3 CA, all the panels had statistically equivalent IB values. Again, no clear correlations were explored between IB and loading level. Moreover, no significant difference in the IB values was observed between type A and type F panels for both preservatives, implying that the treatment of core strands in type A panels did not affect the bonding strength.

Thickness swelling

Both the control and treated groups had very low thickness swelling, ranging from 2.4% to 5.3% after soaking in water for 24 h (Table 2). The thickness swelling was far below the maximum value (12%) allowable in the standard LY/T 1580 (2010) for OSB/4 (Table 2). Type A panels containing 3.0 kg/m^3 ACQ and 2.2 kg/m^3 CA had values of TS as low as the control, while other panels had slightly higher TS than the control. Significant differences in TS values were only observed between CA-treated type F groups and the control, where the former had significantly higher TS than the latter; there were insignificant differences among the rest of the panels. Nevertheless, this difference will have no implication in practice as the TS values of all panels were extremely low.

In short, most of the treated panels had better or comparable physical and mechanical properties compared with the control, indicating that the pretreatment did not have negative effects on the physical and mechanical properties of the investigated bamboo OSB panels. Generally, preservative-treated wood is harder to bond than untreated wood because of possible chemical or physical interference of the preservative with the adhesive and/or the reduction in the wettability of the treated wood (Lorenz and Frihart 2006). For example, the bonding of PRF with ACQ- and CA- treated southern yellow pine was reported to be poorer than that of untreated wood (Lorenz and Frihart 2006). However, the effects of preservatives on bonding rely not only on preservative characteristics themselves and the treatment method, but also on wood species and resin types (Lee *et al.* 2006). PF-bonded laminated lumber with ACQ- and CA-treated southern pine veneers and PF-bonded wood blocks from CA-treated wood were reported to have comparable properties with untreated samples (Lee *et al.* 2006; Shukla and Kamdem 2012). These results agree quite well with the findings from this work. It may be concluded that pretreatment with ACQ and CA within the investigated loading levels may not have detrimental effects on the physical and mechanical properties of bamboo OSB. In contrast, the post-treatment of vacuum-impregnation with ACQ (retentions: 0.65, 1.30, and 2.60 kg/m^3) and CA (0.25, 0.50, and 1.0 kg/m^3) was found to have negative effects on the MOE and MOR of OSB (Taşçioğlu 2013). Tascioglu and Tsunoda (2010a,b) also concluded that post-treatment with CA and ACQ was impractical for OSB because of the resulting high thickness swelling. Compared with those reported disadvantages of post-treatment with ACQ and CA, the pre-treatment process demonstrated herein is a more promising way to introduce waterborne ACQ and CA to protect OSB products. However, considering the high intrinsic property variability of OSB panels (Jin and Dai 2010), a larger size of specimens is recommended in further work to validate the findings of this study regarding to the impact of the preservative treatment on the physical and mechanical properties of bamboo OSB.

CONCLUSIONS

1. The decay resistance of bamboo OSB panels was enhanced by strand pretreatment with both ACQ and CA. Treated bamboo OSB panels had lower mass losses compared with the control, and higher loading levels generally resulted in higher efficacy against decay fungi. Panels with treated strands only in the face layers had strong decay resistance, especially at high loading levels.

2. Pre-treatment with ACQ and CA within the loading levels of this work did not have adverse effects on the mechanical properties**.** No significant differences were found between the physical and mechanical properties of panels with 100% treated strands and those with face treated strands. Hence, making bamboo OSB with only face strand treatment may be economically more viable.
3. Compared with the negative effects of post-treatment with ACQ and CA on OSB, this pretreatment technique is a more promising way to introduce waterborne ACQ and CA to protect bamboo OSB.

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