PERFORMANCE OF ZINC BORATE-TREATED ORIENTED STRUCTURAL STRAW BOARD AGAINST MOLD FUNGI, DECAY FUNGI, AND TERMITES – A PRELIMINARY TRIAL

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The performance of zinc borate (ZB)-treated oriented structural straw board (OSSB) against mold fungi, decay fungi, and termites was examined in standard laboratory evaluations. OSSB was fabricated with split wheat straw strands and diphenylmethane diisocyante (pMDI) resin. The ZB was added during panel manufacture to achieve preservative levels (wt.%) of 1.0%, 1.5%, 2.0%, and 3.0%. It was observed that after a four-week exposure to mold fungi all samples had some mold coverage, but the coverage on the ZB-treated samples was significantly lighter compared to the untreated OSSB. Decay test showed that the weight losses of ZB-treated OSSB blocks at 1.0% and 1.5% levels were significantly reduced compared to the untreated OSSB and solid wood controls, indicating superior performance of ZB-treated OSSB against decay fungi. The termite mortality indicated that none of the termites were alive at the conclusion of the test for ZB-treated OSSB. The results from these specific laboratory studies demonstrated that ZB retentions of 1.5% and greater provide performance against decay fungi and termites for OSSB panels. In addition, untreated OSSB has high susceptibility to mold due to the chemical features of wheat straw and incomplete removal of kernels.

Keywords: Oriented structural straw board; Zinc borate; Mold; Decay; Termite

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INTRODUCTION

In recent decades, due to the shortage of wood resources and environmental impact from burning agricultural residues in China, there has been significant work carried out on straw-based composites (Han 2001; Zhang *et al.* 2003). One possible area for straw-based panels to enter the industry is the structural panel market. The world's first oriented structural straw board (OSSB) manufacturing plant has been operating in China since October 2009. The OSSB product is comparable to wood-based oriented strand board (OSB) in both physical and mechanical properties at comparable densities (Wasylciw 2001 and Han *et al.* 2010a). OSSB is therefore considered as a new building material in China (Han *et al.* 2010a and 2010b).

The demand for housing in China has forced the excavation of food-producing land for clay brick-making, which has caused severe environmental problems and scarcity of agricultural land; however, buildings constructed of brick and cement are susceptible to earthquakes. Thousands of homes made of bricks and cement were badly damaged in the earthquakes in Sichuan, China in 2008. By using waste straw to produce OSSB building panels, Chinese people are creating a new value in reducing carbon emissions from burning straws and from brick production. The development of OSSB technology in China is turning a regional waste into a building product, while reducing its carbon footprint and providing much-needed housing. As a low-carbon building material, OSSB has recently been proposed for use in earthquake-resistant construction and low-cost housing for farmers in rural areas in China (Han *et al.* 2010a).

Similar to wood OSB, OSSB is extensively used for wall, roof, and floor sheathing in both residential and commercial construction. The OSSB framing and sheathing elements are intended for use in dry service conditions, and they can certainly tolerate brief periods of wetting during construction; however, they will suffer from mold, stain, and decay under prolonged exposure to high relative humidity and/or liquid water. OSSB is subject to biological attacks due to the chemical composition of the straw material. It is reported that wheat straw has a higher content of sugars and starches, especially in its kernels (Rowell *et al.* 1997). Complete removal of kernels has proven to be a daunting task in the industrial production of OSSB; therefore, OSSB has a high risk of fungal and termite attacks as long as the kernels are present in the panel.

The wood panel industry has minimal experience in producing wood preservative-treated OSB compared with the significant body of work on the preservative treatment of solid lumber and plywood. Some work has been done to combine powdered borate with wood flakes during the manufacturing of OSB to provide termite and decay resistance of the finished products (Laks *et al.* 1991; Laks *et al.* 1995; Sean *et al.* 1999). Morris (1995) reviewed the literature on processes to improve the durability of OSB. The work concluded that the most promising option for moderate decay hazards was the use of leach-resistant borates such as zinc borate (ZB) during panel manufacture. This was based on the efficacy and low mammalian toxicity of this chemical. More detailed information on ZB treatment and performances were reported by Laks and Manning (1995) and Lee *et al.* (2004). However, no research work has been reported for the preservation of OSSB panel so far.

The objective of this work was to investigate the practical feasibility of using ZB as preservative in OSSB manufacture. The effects of various ZB loading levels on the performance of OSSB against mold fungi, decay fungi, and the Formosan subterranean termite were evaluated.

EXPERIMENTAL

OSSB Manufacturing

Wheat (*Triticum aestivum* L.) straw was collected from Shanxi, China. Prior to straw splitting, the straw was adjusted to a moisture content (MC) of 8% to 10% to avoid the generation of more fines. The straw was longitudinally split using a Straw Splitter at Alberta Innovates Technology Futures (AITF). The split straw was screened on AITF's BM&M deck screener, and the fines (particle size smaller than 3.175 mm) were added back to face and core blends at 20%. The OSSB was fabricated with split straw and diphenylmethane diisocyante (pMDI) resin at the pilot plant of AITF. Split straw strands received 5% pMDI (Huntsman, R1840) resin and 1% E-wax (H&R viva 9373). The zinc borate ($2ZnO \cdot 3B_2O_3 \cdot 3.5H_2O$) provided by Rio Tinto Minerals was used as a preservative additive. The target loading levels for ZB were 0.0%, 1.5%, 2.3%, 3.0%, and 4.5% based on the oven-dry straw weight in the panel. Because of the high efficiency air removal systems in the blender, some of the ZB was lost and the actual chemical retentions were lower than the target: 1.0%, 1.5%, 2.0%, and 3.0% respectively. Control boards were manufactured with no ZB addition. The order of application was water, wax, resin, and then ZB (if applicable) for both ZB and control groups. After blending, the strands were machine-formed into oriented mats with 30% of the mass in each face layer and 40% of the mass in the core layer (*i.e.*, faces/core: 60/40 split). All panels were 2400 mm x 1200 mm x 12 mm in dimension and 552 kg/m^3 in density. Two replicate panels at each ZB level were constructed. The pressing time was 6 min at a temperature of 200^oC. All the boards were cooled and conditioned at 20^oC and 65% RH prior to testing.

Boron Analysis

OSSB samples (50.8 × 50.8 × 12 mm) were cut from four different locations of each panel for boron chemical analysis. The samples were Wiley-milled to pass through a 20-mesh screen. Five grams of straw meal were selected and placed in a flat-bottom flask with a solution of 100 mg of 1N HCl. The flask, connected to a water-cooled condenser, was heated on a heating mantle for 2 h at 100^oC for digesting. The flask was then cooled for 30 min while maintaining seals between the flask and the condenser. The digested samples were finally filtered using Whatman #2 filter paper over a filter funnel, and the analyte was analyzed by an Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) to determine levels of boron and zinc in the sample.

The percentages of boron and zinc were determined on the basis of the molecular weight of ZB. The boron/zinc (B/Zn) ratios were calculated from the percentage of each element. The percentage of boron was finally converted to a boric acid equivalent (BAE). The assay results obtained are an average of four different chemical assays on each of the eight ZB-treated OSSB panels.

Mold Resistance Test

Mold resistance test for OSSB and pine sapwood (as comparison) was carried out according to AWPA standard E24-06 (AWPA, 2006). The following four common fungi were used:

1. *Aureobasidium pullulans*
2. *Penicillium citrinum*
3. *Aspergillus niger*
4. *Alternaria tenuissima*

The mold fungi were mixed with distilled water and sprayed onto a soil bed within a mold chamber. The treated samples were suspended over the soil bed to allow mold growth under a controlled temperature of 25^oC and relative humidity (RH) of 80%. Samples were evaluated weekly for fungal growth. Visual ratings were made using the following criteria (complete description of visual rating scheme given in the AWPA Standard):

Rating
1. No visible growth
2. Mold covering up to 10% of the surface
3. Mold covering between 10% and 30% of the surface
4. Mold covering between 30% and 70% of the surface
5. Mold on greater than 70% of the surface
6. Mold on 100% of the surface

Decay Resistance Tests

Soil block decay tests

Soil block decay tests for ZB-treated and untreated OSSB were conducted at Oregon State University according to the AWPA standard AWPA E10-01 (AWPA, 2001). Pine and poplar sapwood controls were also used as comparison controls in the tests. Two fungal species were used in this study. One was the white rot fungus *Trametes versicolor* (ATCC 42462), while the other was the brown rot fungus *Gloeophyllum trabeum* (ATCC 11539). *G. trabeum* is one of the more borate-tolerant fungi (Cockroft 1974) and *T. versicolor* is a test fungus that preferentially grows on hardwoods. In addition to OSSB samples, both poplar and pine blocks were used as comparison controls. The former was used for the white rot, whereas the latter was used for the brown rot according to AWPA E10-01. The samples were exposed to either the brown rot fungus for 12 weeks or the white rot fungus for 16 weeks. For each treatment, three replicates were conducted for each fungus species.

Each 250-mL Pyrex® glass jar was filled with 33 g of distilled water and 100 g of oven-dried fresh forest soil. The mixture was stored overnight until the water was evenly soaked by the soil. A feeder strip was then placed on the soil in the jar. The poplar strips were used for the white rot, and the pine strips for the brown rot. All jars were closed with plastic caps and steam-sterilized at 122^{o}C under a steam pressure of 120 KPa for 30 min and then gradually cooled to room temperature. The white-rot and brown-rot fungi were transferred onto a feeder strip in each soil-block jar under a sterile hood. The fungi were then incubated at 27^{o}C and a relative humidity 80% for three weeks until each strip was covered with a mycelium mat.

The test samples for the soil-block tests were measured 25 mm long by 16 mm wide by 3 mm thick. Each sample was sanded before exposure to the fungi. Each labeled test specimen was oven-dried at 40^{o}C to reach a constant weight (W_1), which was the initial weight before the decay test. All test samples were wrapped in groups in aluminum foil and autoclaved at 100^{o}C for 20 min. After cooling to room temperature, each sample was placed into a soil-block jar under the sterile hood. All test jars were placed in a controlled condition chamber at 27^{o}C and a relative humidity 80% for 12 or 16 weeks depending on the fungi.

After decay resistance testing, all tested samples were removed from the test jars. Each specimen was carefully cleaned with a piece of soft paper to remove the mycelium from the sample surface. It was then stored at room temperature for 24 h and oven-dried at 40^{o}C to reach a constant weight (W_2). The weight loss of each sample was calculated using Eq. 1:

$$\text{Weight loss (\%)} = [(W_1 - W_2)/W_1] \times 100 \quad (1)$$

where, W_1 = sample weight prior to the decay test (g); and W_2 = sample weight after the decay test (g).

The decay susceptibility index (DSI) was calculated using Eq. 2 according to the standard ENV 12038.

$$\text{DSI (\%)} = (\text{mass loss of sample / mass loss of reference sample}) \times 100 \quad (2)$$

EN 113 decay test

The European version of the laboratory soil block decay test was also carried out at RTM's laboratory in Denver, Colorado according to European standard EN 113. In this exposure the OSSB, pine, or poplar samples were exposed to the brown rot fungus *Postia placenta* for 12 weeks or the white rot fungus *Irpex lacteus* for 16 weeks.

Termite Resistance Test

Termite tests were conducted at the University of Hawaii in accordance with AWPA E1-97 (AWPA 1997) by exposing the OSSB samples to the Formosan subterranean termite (*Coptotermes formosanus*). Two sets of specimens (17.8 × 17.8 × 12 mm), with five replicates in each group, were prepared from the OSSB panels with ZB retentions of 0, 1.0, and 1.5%. One set was used for the termite tests, and the other set for moisture content determination. Each block was identified with a label on the sample surface. Five samples of untreated OSSB were used as controls in this study.

Each test bottle (80 mm in diameter × 100 mm in height) was autoclaved for 30 min at 105 KPa and then dried. Autoclaved sand (150 grams) and distilled water (30 mL) were added to each bottle. A single-choice procedure was used with one test block placed on a foil base slightly larger than the test specimens on the surface of the sand in each bottle, prior to the placement of termites.

Four hundred termites (approximately 360 workers and 40 soldiers) were added to the opposite side of the test block in the container. All containers were maintained at 26^{o}C and 90% RH for four weeks. The bottle caps were placed loosely onto the container to allow for some air exchange. After the 28-day termite test, the bottles were dismantled. Live termites were counted and test blocks were removed and cleaned, using a small brush and rinsed with distilled water.

Termite mortality was determined as a ratio of the number of living termites to the initial termite number (400) and subtracted from 1.00. Test blocks were visually rated by five different observers according to AWPA E1-97 (AWPA 1997).

RESULTS AND DISCUSSION

Mold Resistance

The results of chemical assays and mold evaluation are summarized in Table 1. Chemical assays were made on all OSSB samples that were exposed in the test. As previously described, actual ZB retentions were lower than their target loading levels.

Visual and coverage ratings of mold presence indicated a close response associated with ZB loadings. The untreated OSSB (0.0% ZB application) showed little resistance to mold exposure and became rapidly covered with mold. After four weeks of exposure at conditions of 33^{o}C and 100% RH, OSSB containing ZB loadings of 1.5% and greater showed some resistance to mold growth compared to the untreated control panels. Both visual and coverage ratings of untreated OSSB had higher values than the pine control samples, indicating faster mold growth on OSSB than on the solid wood. The inferior mold resistance of straw board can be attributed to the chemical features of wheat straw. It is reported that wheat straw has a higher content of sugars and starches, especially in its kernels (Rowell *et al.* 1997); therefore, OSSB exhibits high susceptibility to contamination by mold fungi as long as the kernels are present in the panel. It is recommended to avoid the use of kernels as much as possible in OSSB production. Mold and stain control can also be accomplished by spray application of moldicides to the board surface (Morris 1995).

Table 1. Summary of Results for a Four-week Laboratory Efficacy Test on Mold Resistance to ZB-treated OSSB

Actual ZB Level [%]	Actual BAE [%]	Weekly Visual and Coverage Ratings							
		1st Week		2nd Week		3rd Week		4th Week	
		Visual	Cover	Visual	Cover	Visual	Cover	Visual	Cover
0.0	0.00	4.00	4.33	5.00	5.00	5.00	5.00	5.00	5.00
1.0	0.85	3.00	3.00	3.67	3.67	4.00	5.00	3.33	5.00
1.5	1.28	1.67	2.00	2.00	3.00	3.00	3.00	3.33	4.00
2.0	1.71	1.33	2.00	1.33	2.33	2.00	2.33	2.33	3.33
3.0	2.56	1.00	1.33	1.00	2.00	1.67	2.00	2.00	3.33
Pine control	N/A*	0.00	0.33	0.67	0.67	2.33	1.67	2.33	4.00
* N/A - not applicable									

Decay Resistance

The results on weight loss of ZB-treated OSSB after decay resistance testing are displayed in Table 2 and Fig. 1. Weight losses caused by *G. trabeum* and *T. versicolor* on the pine sapwood blocks averaged 38.76 and 39.91%, respectively. These weight losses indicate an aggressive decay environment and positive fungal viability. Weight losses for the untreated OSSB samples exposed to *G. trabeum* and *T. versicolor* were 56.29 and 67.43%, respectively, indicating that the untreated OSSB had no decay resistance. Untreated OSSB that was evaluated as environmental controls (all other test conditions were the same, just no fungus) exhibited a weight loss of 5.71%, indicating that there were levels of water-soluble extractives in the OSSB. Weight losses for the ZB-treated OSSB blocks exposed to both fungi were significantly reduced compared to the untreated OSSB and pine control, indicating superior decay resistance performance of ZB-treated OSSB. The decay susceptibility index (DSI) also showed that the decay susceptibility significantly decreased for the ZB-treated OSSB. Weight losses for the OSSB environmental control samples (no exposure to fungus) with 1.0 and 1.5% ZB were 6.01 and 6.68%, respectively, indicating that the small weight losses in the blocks exposed to decay fungi could be attributed to leaching and not biological attack. Similar results were also obtained in the EN 113 decay test.

The improved decay resistance of ZB-treated OSSB is due to the chemical action of ZB in the panel. The typical formula of ZB is $xZnO \bullet yB_2O_3 \bullet zH_2O$. Like other boron compounds, ZB inhibits enzymatic reaction of fungi and insects. ZB forms stable complexes with vitamins, coenzymes or other biological molecules having polyol groups and simultaneously inhibits metabolic activity, enzymatic function, and growth of fungi. Therefore ZB acts more as fungistatic agent that has an inhibiting effect upon the growth and reproduction of fungi without destroying them, rather than acting as a fungicide.

Table 2. Summarized Data for Decay Resistance Test of ZB-treated OSSB

ZB Level [%]	AWPA E10 Soil Block Test					EN 113 Decay Test				
	G. trabeum		*T. versicolor*		No fungus	*P. placenta*		*I. lacteus*		No fungus
	WL*[%]	DSI**	WL[%]	DSI	WL[%]	WL[%]	DSI	WL[%]	DSI	WL[%]
0.0	56.29 (3.04)	145.23	67.43 (2.88)	168.96	5.71 (0.39)	6.17 (1.67)	14.68	50.46 (5.49)	110.05	1.57 (0.60)
1.0	9.88 (3.88)	25.49	5.51 (1.55)	13.81	6.01 (0.31)	6.01 (1.47)	14.30	5.72 (1.33)	12.48	1.09 (0.30)
1.5	7.20 (0.38)	18.58	6.69 (0.71)	16.76	6.68 (0.48)	5.32 (0.61)	12.65	6.78 (1.50)	14.79	2.43 (0.33)
Pine	38.76 (6.47)	--	39.91 (6.64)	--	--	42.04 (8.41)	--	--	--	--
Poplar	--	--	--	--	--	--	--	45.85 (7.30)	--	--

* Each mean (±SD) of weight loss (WL) represents three replicates of OSSB and solid wood samples.
** DSI = decay susceptibility index

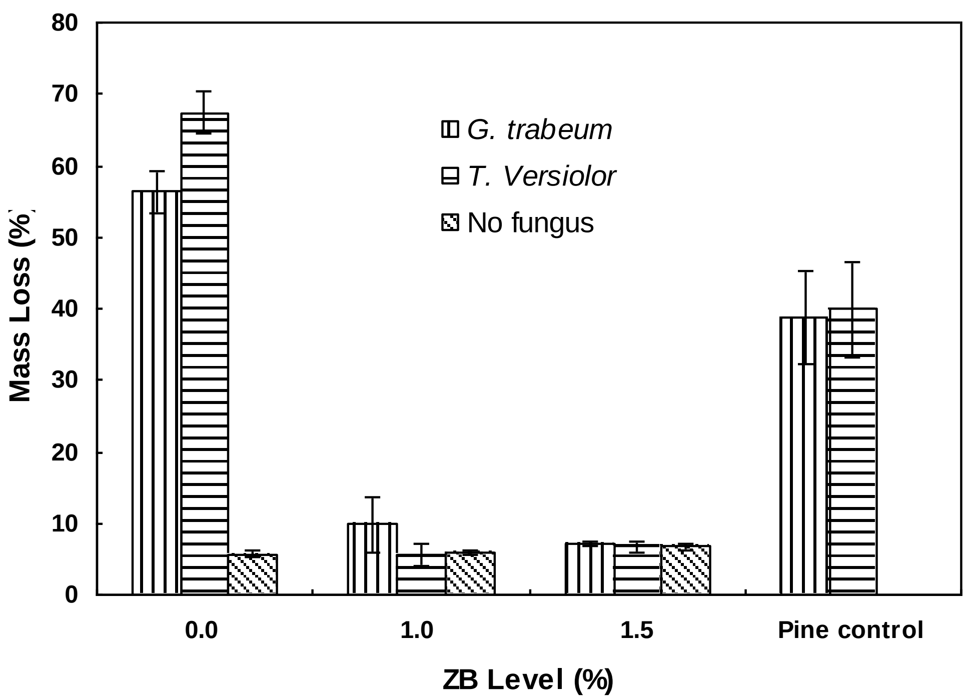

Fig. 1. Mass loss of untreated OSSB, pine solid wood, and ZB-treated OSSB exposed to the brown and white rot fungi in an AWPA E10 soil block test

Termite Resistance

A summary of results for a four-week laboratory efficacy test for Formosan subterranean termite resistance to ZB-treated OSSB is shown in Table 3. Visual termite ratings for the OSSB samples with actual ZB retentions of 0.0, 1.0, and 1.5% were 6.6, 8.2, and 8.4, respectively. These visual ratings were carried out using the AWPA 0 to 10 rating scale, with a rating of 0 indicating complete destruction of the sample and a rating of 10 indicating no evidence of termite attack. The 8.2 and 8.4 ratings are consistent with a level of termite nibbling that is often seen with borate-treated samples in lab and field evaluations

Termite mortality was also recorded at the conclusion of the 28-day test, indicating the number of dead termites out of the 400 termites (360 workers and 40 soldiers) specified in the test protocol. The 0.0, 1.0, and 1.5% ZB-treated OSSB samples exhibited termite mortality of 24.6, 100.0, and 100.0%, respectively. Higher termite mortality is a positive result. For the ZB treated samples, none of the termites were alive at the conclusion of the test.

Table 3. Formosan Subterranean Termite Resistance of ZB-treated OSSB

Actual ZB level [%]	Rating *	Termite mortality [%]
0.0	6.6	24.6
1.0	8.2	100.0
1.5	8.4	100.0
* Rating – Based on 0-10 scale with 0 denoting the most damage		

The termite results described here are laboratory studies. Field studies evaluating the performance of ZB-treated OSSB against an active Formosan subterranean termite colony are currently being carried out, and these results will be reported in the future.

CONCLUSIONS

From the results obtained, the main conclusion is that retention of 1.5% ZB provides performance against decay fungi, mold fungi, and termites for the OSSB samples evaluated. Addition of ZB should be carried out so as to ensure that a minimum retention of 1.5% ZB is achieved in the OSSB. The specific findings can be drawn as follows:

1. OSSB containing ZB loadings of 1.5% and greater showed some resistance to mold growth compared to the untreated control panels.
2. The untreated OSSB had inferior mold resistance compared to solid wood due to the chemical features of wheat straw and incomplete removal of kernels.
3. Superior performance against decay fungi was observed for ZB-treated OSSB at 1.0% and 1.5% ZB retentions compared to untreated OSSB and solid wood controls.
4. The termite mortality indicated that none of the termites were alive at the conclusion of the test for ZB-treated OSSB.

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