THE EFFECTS OF COPPER-BASED PRESERVATIVE TECHNOLOGIES ON THE RESISTANCE OF ASPEN STRANDBOARDS TO BIOLOGICAL DEGRADATION

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Abstract. Mold and decay resistance of aspen strandboards treated with various copper-based preservative systems were evaluated in laboratory tests. Five copper-based chemicals or zinc borate were blended into the aspen furnish at three retention levels. Tebuconazole or 4,5-dichloro-2-N-octyl-4-isothiazolin-3-one (DCOI) were added as cobiocides to selected copper-based treatments. Panels were inoculated with four common molds and subjected to high temperature and humidity for 8 wk according to AWPA Standard E24. Most panels experienced extensive mold growth, but panels treated with DCOI had marked resistance to attack as did combinations of copper-based preservatives and DCOI. Panels were also assessed for decay resistance in a laboratory soil-block test against the brown-rot fungus *Gloeophyllum trabeum* or the white-rot fungus, *Trametes versicolor,* according to AWPA Standard E10. All preservatives reduced weight losses caused by *G. trabeum* or *T. versicolor* below 10%, except for micronized copper hydroxide or DCOI alone. The four other copper-based preservatives performed well independently and with the addition of DCOI or tebuconazole. The results suggest that incorporating combinations of copper-based preservative systems with organic cobiocides improved decay and mold resistance of aspen-oriented strandboard.

Keywords: Oriented strandboard, OSB, copper ammine, zinc borate, DCOI, isothiazolone, tebuconazole, durable composites, mold resistance, aspen, *Populus tremuloides*.

INTRODUCTION

Although wood and wood-based composite sheathing panels can tolerate brief periods of wetting during construction, they are designed to remain dry while in service. Exposing these products to high RH or liquid water for prolonged periods sharply increases the chances of mold, stain, or decay (Morris et al 1999; Fogel and Lloyd 2002). Softwood plywood panels tend to be more resistant to decay and mold than

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OSB (Laks 1999; Laks et al 2002). Although OSB and strand-composite products are made from decay-susceptible species, they are increasingly being used in applications that subject them to conditions that could promote insect and fungal attack.

A variety of methods can be used to protect composite panels from biological attack (Gardner et al 2003). In-process treatments appear to be among the best methods. Uniform preservative distribution within the product provides much better protection than "shell" treatments provided by posttreatment processes, but pretreating the substrate requires an extra drying step that is energy-intensive and costly (Laks and Palardy 1992).

There are a number of preservatives that may be suitable for in-process treatment of composite panels. Each has advantages and disadvantages in terms of cost, safety, ease of handling, and efficacy. Organic biocides are increasingly used as wood preservatives because of their low toxicity to nontarget organisms and rising consumer concerns about the use of heavy metals. Triazoles are a class of organic fungicides that are widely used in agriculture and are increasingly used as cobiocides in wood preservatives. These systems provide adequate protection against decay fungi, moderate protection against surface mold, and little degradation of mechanical or physical properties of OSB (Schmidt and Gertjejansen 1988; Tolley et al 1998). Isothiazolones are broad-spectrum fungicides that reduce mold growth (Williams and Lewis 1989) and are effective against decay fungi in both laboratory and field tests (Leightley and Nicholas 1990).

Borates have a number of appealing benefits as wood preservatives, including good efficacy against fungi and insects, fire retardancy (at high levels), ease of addition to board furnish, low cost, low mammalian toxicity, and low environmental impact (Laks and Palardy 1990). However, borates have a few disadvantages that limit them as composite panel preservatives. Biologically effective treatment levels of sodium borate and boric acid react with phenol formaldehyde resin to prevent good adhesion between wood substrates, resulting in boards with unacceptably low mechanical properties. A number of borate treatments, including disodium octaborate tetrahydrate and anhydrous borax, are extremely water-soluble and therefore have a propensity to leach in-service (Gardner et al 2003). As a result, these products are not recommended for wood used in ground contact. As an alternative, zinc borate (ZnB) is a relatively water-insoluble alternative that is currently used in coated exterior applications with low to moderate leaching hazards (Manning and Laks 1996; Laks 1999). Various physical or chemical modifications have also been assessed for OSB protection, including acetylation, isocyanates, supercritical fluids, and heat treatment (Murphy and Turner 1989; Kumar and Morrell 1993; Acda et al 1996; Paul et al 2006). None of these treatments is currently practical as a result of unacceptable weight gains and/or cost.

Powdered forms of copper preservatives have shown good efficacy when included in wood-based composites (Schmidt 1991; Kirkpatrick and Barnes 2006). Copper ammonium carbonate was found to be an effective preprocess preservative for OSB, but the added processing steps made the panel uneconomical (Preston et al 2003). Adding copper carbonate hydroxide-based preservatives with boric acid, tebuconazole, and an aliphatic amine derivative as cobiocides at various points during the manufacturing produces decay-resistant panels, but the mechanical properties are reduced (Goroyias and Hale 2000). Copper-based biocides, preferably in powder form that can be added to the furnish, appear to have strong potential as a composite panel preservative if formulation and application methods can be optimized.

The objective of this research was to evaluate the effects of incorporating various copper-based preservatives into the furnish, with or without organic cobiocides, on the mold and decay resistance of aspen strandboards.

MATERIALS AND METHODS

Panel Fabrication

Commercially manufactured aspen strands obtained from Louisiana-Pacific (Newberry, MI) were dried at 70°C to approximately 3% MC and stored in plastic bags until use.

Preservatives were acquired from Viance LLC (Charlotte, NC) and Rio Tinto Minerals, Inc. (Edgewood, CO). Seven chemicals were incorporated individually or in combination into board furnishes at various target concentrations (Table 1) and compared with untreated negative controls and zinc borate-treated positive controls. Each of the 26 treatment groups were replicated on six panels.

A 2-m-dia rotary blender was used and each furnish batch was capable of producing three panels (strands, preservative, wax, and resin). The strands were added first, and then dry salts of treatment chemical were sprinkled over the mixture. The preservative and the strands were then blended for 5 min at 16 rpm. An air atomization nozzle attached to the inside of the blender was used to spray the liquid copper complex onto the tumbling strands. 4,5-Dichloro-2-N-octyl-4-isothiazolin-3-one (DCOI) was added to the wax emulsion.

Wax emulsion (58% solids content; Hexion Specialty Chemicals, Springfield, OR) was sprayed on the tumbling strands using the air atomization nozzle at a loading of 1.0% wt/wt. OSB face resin with 48% solids content (Georgia-Pacific, Albany, OR) was then applied to the strands at a loading of 3.5% wt/wt through a spinning disk atomizer at 6000 rpm during blending.

The strands were randomly distributed in a 560-mm-square forming box, steel caul plates were placed on either side, and the materials were pressed at 200°C for 200 s. Because of the difficulties in producing acceptable boards using DCOI, press time was increased to 400 s for these panels. A second untreated control group was also pressed for the extended time. The press was then vented by opening at a rate of 0.02 mm/s for 60 s to produce finished boards that were approximately 12.7 mm thick and had a density of approximately 577 kg/m^3. Approximately 90 mm was trimmed from each edge of the board using a table saw. Specimens were then cut from the panels for biological tests. Decay test blocks were 19 × 19 × 12.7 (thick) mm, whereas mold test samples were 50 × 100 × 12.7 (thick) mm. One mold test specimen and four decay test specimens were cut from each of the six panels per treatment. The remaining materials were used for separate testing of physical properties (Vidrine et al 2008).

Loading Analysis

The levels of each preservative component in the panels were determined using the appropriate analytical method. Copper was determined by X-ray fluorescence spectroscopy according to AWPA Standard A9 (AWPA 2004b). ZnB-treated wood was extracted by nitric acid digestion (AWPA 2004a) and analyzed by inductively coupled plasma emission spectrometry following AWPA Standard A21 (AWPA 2004c). DCOI and tebuconazole were extracted in methanol; the resulting extracts were analyzed by high-performance liquid chromatography with ultraviolet detection according to AWPA Standard A30 or Standard A28, respectively (AWPA 2004d, 2004e).

Soil-block Test

Unleached test blocks were oven-dried (105°C), weighed, and sterilized by gamma irradiation before being exposed to the brown-rot fungus *Gloeophyllum trabeum* (Pers.ex. Fr.) Murr. (Isolate Madison 617) or the white-rot fungus *Trametes versicolor* (L. ex Fr.) Pilát (Isolate FP-101664-Sp) according to procedures described in American Wood Protection Association Standard E 10 (AWPA 2004f). The samples were incubated at 28°C for 12 and 16 wk for the brown- and white-rot fungi, respectively. Percentage weight loss of the blocks was used as a measure of decay resistance. Ponderosa pine sapwood cubes (19 mm) were included as comparator controls. Each treatment variable was evaluated on six blocks per test fungus except

Table 1. *Sources and amounts of chemicals mixed with aspen furnish to make strandboards.*

Treatment	Abbreviation	Loading (%wt/wt)[ab] Target	Loading (%wt/wt)[ab] Actual	Mat MC (%)[a,c]	Manufacturer
Zinc borate	ZB	0.281/0.422/0.563	0.214/0.275/0.395	7.4/7.4/7.3	Rio Tinto Minerals
Cu ammonium acetate complex (liquid)	CC1	0.25/0.50/0.75	0.18/0.33/0.49	10.2/13.1/16.0	Viance LLC
Cu diammine acetate	CC2	0.25/0.50/0.75	0.09/0.15/0.29	7.4/7.3/7.3	Viance LLC
Cu diammine carbonate	CC3	0.25/0.50/0.75	0.10/0.23/0.35	7.4/7.3/7.3	Viance LLC
Micronized Cu hydroxide	MCOH	0.25/0.50/0.75	0.04/0.06/0.12	7.4/7.3/7.3	Viance LLC
Basic Cu carbonate	BCC	0.25/0.50/0.75	0.10/0.17/0.24	7.4/7.4/7.3	Viance LLC
Cu diammine acetate/ tebuconazole	CC2/azole	0.5/0.01, 0.5/0.02, 0.5/0.04	0.19/0.006, 0.22/0.012, 0.24/0.024	7.3/7.3/7.3	Viance LLC
Isothiazolone	DCOI	0.05	0.024	6.7	Viance LLC
DCOI/Cu diammine acetate	DCOI/CC2	0.05/0.5	0.025/0.16	6.6	Viance LLC
DCOI/Cu ammonium acetate (liquid)	DCOI/CC1	0.05/0.5	0.027/0.38	12.4	Viance LLC
None	Control (200 s)	—	—	7.4	—
	Control (400 s)	—	—	5.7	—

[a] Values represent the percentage of each component in the order listed in the first column.
[b] Loading is expressed as the percentage preservative on the following bases within the panel: ZB as boric acid equivalent (BAE), copper as %Cu, tebuconazole and isothiazolone as percent active ingredient.
[c] Mat MC is based on oven-dry weight of wood plus moisture levels in other components as provided by the suppliers.

for the isothiazolone and untreated controls at 400 s, which were tested on five blocks. Fungal thresholds for each chemical were estimated by determining where no fungal induced weight loss was evident

Mold Box Test

The AWPA Standard E24-06 mold box test is a relatively rapid method for determining the resistance of wood-based material surfaces to mold fungi (AWPA 2007). Samples (75 × 100 mm) were sprayed with an inoculum solution containing the common molds *Aureobasidium pullulans* (d. By.) Arnaud, *Aspergillus niger* vs Tiegh., *Penicillium citrinum* Thom, and *Alternaria alternata* (Fr.) Keissl. The samples were then suspended above moist soil within a sealed box maintained at 25°C and the room was maintained at 20°C, resulting in elevated RH and the potential for condensation. The samples were incubated for 8 wk and were inspected every 2 wk by visually assessing both broad surfaces of each sample for degree of discoloration based on the following scale:

Rating Description
(i) 0 = No mold growth
(ii) 1 = Mold on <10% of surface
(iii) 2 = Mold on 10 – 30% of surface
(iv) 3 = Mold on 30 – 70% of surface
(v) 4 = Mold on >70% of surface
(vi) 5 = Mold on 100% of surface

Statistical Analysis

Differences between treatments and the control groups were assessed using a completely randomized design analysis of variance using SAS 9.1 (α = 0.05; SAS Institute 2005). Duncan's multiple range test was used to determine differences between treatment means.

RESULTS AND DISCUSSION

Loading Analysis

Actual loadings tended to be lower than target loadings except for ZnB (Table 1). Loadings were closest to the target in panels treated with copper diammine acetate (CC 1) possibly because the material was sprayed onto tumbling flakes, but even these levels were 27 – 35% below target levels. CC 2, CC 3, and basic copper carbonate (BCC)-treated panels were 53 – 71% below target loadings. Insufficient preservative adherence to the strands, even after the addition of wax and resin, may have been one cause for the low loadings. Micronized copper hydroxide (MCOH) loadings were up to 89% below the target level. DCOI was added to the wax and was assumed to have good distribution onto the strands with minimal loss. The lower DCOI loadings may have been the result of degradation of the biocide during exposure to high temperatures in the press.

Soil-block Test

Chemical addition significantly improved decay resistant for all fungi species ($\alpha = 0.05$, $p < 0.0001$). Weight losses for both sets of untreated strandboards exposed to *G. trabeum* were greater than 50%, indicating that conditions were suitable for aggressive fungal attack and that the extra press time alone had no effect on decay resistance (Table 2).

All chemical treatments reduced weight losses to below 10%, except panels treated with DCOI alone, MCOH, and the lowest treatment levels of CC 2 and BCC. The DCOI levels used were extremely low and were not intended to provide protection against fungal decay. The poor performance of the particulate copper was initially surprising; however, the results are largely explained by the extremely low copper loadings along with some observed clumping of chemical during mixing. This system was an experimental formulation and is not directly comparable to the micronized copper systems currently in commercial use. Panels treated with combinations of DCOI and the liquid CC 1 performed best against *G. trabeum* with average weight losses below 1%. Panels treated with CC 1 alone experienced similar weight losses, suggesting that DCOI was not needed for decay resistance.

Weight losses from panels treated with tebuconazole and CC 2 were less than 3%, which was not statistically different compared with CC 2 alone at the medium target loading. Increased tebuconazole loading appeared to be associated with reduced weight losses, but these differences were not statistically significant. It is likely that the added fungicide had only a minimal effect because of the protection already afforded by the copper compound. ZnB performed as well as the copper compounds with a maximum weight loss of 6.2% for the lowest target loading, illustrating the excellent performance of this system.

Treated and untreated blocks exposed to *T. versicolor* experienced weight losses similar to those exposed to *G. trabeum*, indicating that conditions were suitable for aggressive fungal attack (Table 2). Weight losses exceeding 50% were found on both untreated strandboard control groups. Pine controls had a mean weight loss of 38%, reflecting the preference of white-rot fungi for hardwoods. ZnB performed exceptionally well against *T. versicolor* at all three levels tested.

All three copper complexes performed well against *T. versicolor* when used alone. Panels treated with CC 1 were more resistant to fungal attack, which may reflect the more even distribution of the liquid treatment in the panels. Like with the brown-rot fungus, MCOH performed poorly against the white-rot fungus with no evidence of a dose–response effect. Low loading levels, as noted earlier, probably played a role in the poor performance of this system.

Panels treated with combinations of DCOI and CC1 or CC 2 performed as well as panels treated with only these copper complexes at the same target loadings. DCOI was added at extremely low levels as a mold inhibitor and its failure to impact performance of copper compounds at this level was not surprising.

Determining threshold values for each of the test compounds was challenging. Thresholds could not be determined for micronized copper as well as the two dual biocide treatments because at least one of the test fungi caused weight losses at the highest level tested. It is important to recognize that, although the target treatment levels were well within the range

Table 2. *Effect of incorporation of biocides into the wood furnish on resistance of aspen strandboard to fungal decay in an AWPA E10 soil-block test.*

Treatment	Actual retention (%wt/wt)[a]	Wood weight loss (%)[b]	
		G. trabeum	*T. versicolor*
Zinc borate	0.214	6.2 (9.6) hi	2.6 (2.1) f
	0.275	1.9 (0.6) i	1.5 (0.2) f
	0.395	1.4 (0.1) i	1.4 (0.1) f
Copper ammonium acetate complex (liquid)	0.18	4.4 (0.7) hi	3.3 (0.3) f
	0.33	3.2 (1.0) hi	2.2 (0.4) f
	0.49	2.4 (0.7) hi	2.2 (0.3) f
Copper diammine acetate	0.09	12.2 (5.6) gh	13.3 (2.7) e
	0.15	3.8 (1.3) hi	6.0 (2.2) ef
	0.29	2.7 (1.0) hi	2.6 (0.7) f
Copper diammine carbonate	0.10	9.4 (2.3) ghi	7.9 (1.7) ef
	0.23	2.8 (0.7) hi	3.7 (1.3) f
	0.35	1.9 (0.4) i	3.4 (0.8) f
Micronized copper hydroxide	0.04	46.0 (16.9) de	29.4 (12.8) d
	0.06	29.6 (14.2) f	33.0 (12.7) d
	0.12	41.8 (23.1) e	41.2 (23.3) c
Basic copper carbonate	0.10	17.4 (3.7) g	8.6 (1.7) ef
	0.17	3.3 (1.3) hi	3.7 (0.9) f
	0.25	2.0 (0.8) i	2.9 (0.6) f
Cu diammine acetate/tebuconazole	0.19/0.006	2.7 (0.6) hi	4.7 (1.2) ef
	0.22/0.012	2.0 (0.3) i	3.2 (0.4)f
	0.24/0.024	1.6 (0.3) i	3.6 (1.6) f
Isothiazolone (DCOI)	0.024	62.4 (7.0) ab	58.6 (5.3) b
DCOI/Cu diammine acetate	0.025/0.16	2.3 (0.7) hi	4.4 (1.8) ef
DCOI/Cu ammonium acetate (liquid)	0.027/0.38	0.8 (0.2) i	1.2 (0.4) f
Control 200 s	—	55.6 (4.4) bc	52.8 (12.0) b
Control 400 s	—	53.5 (12.3) dc	67.8 (11.7) a
Pine Control	—	68.4 (2.1) a	28.4 (5.1) d

[a] Actual retentions is expressed as the percentage preservative on the following bases within the panel: ZB as boric acid equivalent (BAE), copper as %Cu, tebuconazole and isothiazolone as percent active ingredient.

[b] Values represent means of six blocks per treatment per fungus, whereas figures in parentheses represent 1 SD. Values followed by the same letter(s) do not differ significantly from one another using Duncan's multiple range test at $\alpha = 0.05$.

needed to produce protection on solid wood, the actual loadings were far lower and help to explain the inability of the test to produce more precise threshold values. Threshold values for all treatments as determined by procedures described in AWPA Standard E10 ranged from 0.14 – 0.90% (wt/wt) (Table 3).

Mold Box Test

Very few treatments had any effect on mold resistance of strandboards ($\alpha = 0.05$, $p = <0.0001$ at all weeks) (Table 4). After 2 wk in the mold box, ZnB, CC 2, CC 3, MCOH, and basic copper carbonate at all treatment levels received ratings of at least 3, representing between 30 – 70% surface coverage. These treatments all received ratings of at least 4, or greater than 70% coverage, by week 3. CC 1 appeared to reduce mold growth after 2 wk, especially at the highest loading level, possibly because the liquid preservative was more evenly distributed over the strand surfaces. The highest loading level of CC 1 had a rating of 4.2 after 4 wk, indicating that this compound no longer protected against mold growth. Although copper compounds are widely used in heavy-duty wood treatments, they are prone to surface mold growth on prolonged wet storage. This performance attribute appears to extend to copper in panel products.

Boards treated with CC 2 and supplemented with tebuconazole appeared to experience reduced mold growth at 2 wk, but all had experienced substantial mold growth within 3 wk. These data

Table 3. *Estimated thresholds for protection of aspen strandboard against fungal attack as determined using an AWPA E10 soil-block test.*

Chemical treatment	Most aggressive fungus	Estimate threshold (%wt/wt)[a]
Zinc borate	*G. trabeum*	0.90
Copper ammonium acetate complex (liquid)	*G. trabeum*	0.20
Copper diammine acetate	*G. trabeum/T. versicolor*	0.15
Copper diammine carbonate	*P. placenta*	0.25
Micronized copper hydroxide	*G. trabeum/T. versicolor*	NA (>0.12)
Basic copper carbonate	*G. trabeum*	0.14
Copper diammine acetate/tebuconazole	*P. placenta*	NA (>0.24)
DCOI/copper ammonium acetate (liquid)	*P. placenta*	NA (>0.38)

[a] Values determined by graphing results. NA signifies an inability to calculate a threshold because one or more of the fungi could not be controlled at the levels tested.

Table 4. *Effect of incorporation of biocides into the furnish on mold resistance of aspen strandboard as determined in an AWPA E24 mold test.*

Treatment	Actual retention (%wt/wt)[a]	Mold[b] rating				
		Week 2	Week 3	Week 4	Week 6	Week 8
Zinc borate	0.214	3.3 (0.6) bcd	4.0 (0) bcd	4.3 (0.5) abc	5.0 (0) a	—
	0.275	3.7 (0.6) bcd	4.2 (0.4) abcd	4.2 (0.4) abc	4.8 (0.4) ab	—
	0.395	3.7 (0.6) bcd	4.0 (0) bcd	4.5 (0.5) ab	4.8 (0.4) ab	—
Copper ammonium	0.18	3.0 (1.0) cde	4.3 (0.5) abcd	4.5 (0.5) ab	4.8 (0.4) ab	—
acetate complex (liquid)	0.33	3.0 (1.7) cde	4.5 (0.5) abc	4.8 (0.4) a	5.0 (0) a	—
	0.49	1.7 (1.2) f	3.8 (0.8) cd	4.2 (0.4) abc	5.0 (0) a	—
Copper diammine	0.09	4.3 (0.6) ab	4.8 (0.4) a	4.7 (0.5) ab	5.0 (0) a	—
acetate	0.15	4.3(0.6) ab	4.7 (0.5) ab	4.8 (0.4) a	5.0 (0) a	—
	0.29	5.0 (0) a	4.5 (0.5) abc	4.8 (0.4) a	4.8 (0.4) ab	—
Copper diammine	0.10	4.3 (0.6) ab	4.5 (0.5) abc	4.7 (0.5) ab	5.0 (0) a	—
carbonate	0.23	3.7 (0.6) bcd	4.2 (0.4) abcd	4.8 (0.4) a	5.0 (0) a	—
	0.35	4.3 (0.6) ab	4.5 (0.5) abc	4.8 (0.4) a	5.0 (0) a	—
Micronized copper	0.04	3.7 (0.6) bcd	4.2 (0.4) abcd	4.3 (0.5) abc	4.5 (0.5) ab	—
hydroxide	0.06	4.3 (0.6) ab	4.5 (0.5) abc	4.5 (0.5) ab	4.7 (0.5) ab	—
	0.12	4.3 (0.6) ab	4.5 (0.5) abc	4.5 (0.5) ab	4.8 (0.4) ab	—
Basic copper	0.10	4.0 (0) abc	4.2 (0.4) abcd	4.2 (0.4) abc	4.7 (0.5) ab	—
carbonate	0.17	4.0 (0) abc	4.3 (0.5) abcd	4.5 (0.5) ab	4.7 (0.5) ab	—
	0.25	4.0 (0) abc	4.5 (0.5) abc	4.3 (0.5) abc	5.0 (0) a	—
Cu diammine acetate/	0.19/0.006	4.3 (0.6) ab	4.5 (0.5) abc	4.5 (0.5) ab	5.0 (0) a	—
tebuconazole	0.22/0.012	3.0 (1.0) cde	4.2 (0.4) abcd	4.5 (0.5) ab	4.8 (0.4) ab	—
	0.24/0.024	2.0 (0) ef	4.0 (0) bcd	4.0 (0) bc	4.8 (0.4) ab	—
Isothiazolone (DCOI)	0.024	2.5 (0.8) def	3.0 (1.1) e	3.7 (0.5) cd	4.3 (0.5) b	4.7 (0.5) ab
DCOI/Cu diammine acetate	0.025/0.16	1.5 (0.5) f	2.5 (0.5) e	3.3 (0.5) de	3.8 (0.4) c	4.2 (0.4) bc
DCOI/Cu ammonium acetate (liquid)	0.027/0.38	1.3 (0.8) f	1.7 (0.8) f	2.8 (0.8) e	3.3 (0.5) d	3.7 (0.5) c
Control 200 s	—	3.7 (0.6) bcd	3.7 (1.0) d	4.3 (0.8) abc	4.7 (0.5) ab	—
Control 400 s	—	3.8 (0.4) abc	4.2 (0.4) abcd	4.7 (0.5) ab	4.8 (0.4) ab	5.0 (0) a

[a] Actual retentions is expressed as the percentage preservative on the following bases within the panel: ZB as boric acid equivalent (BAE), copper as %Cu, tebuconazole and isothiazolone as percent active ingredient.

[b] Values represent means of six blocks per treatment, wheeras figures in parentheses represent 1 SD. Mold rating range from 0 (no mold) to 5 (completely covered). Values followed by the same letter(s) do not differ significantly using Duncan's multiple range test at $\alpha = 0.05$.

showed that tebuconazole performed poorly as a moldicide, but this might be the result of insufficient target loading levels or actual loadings less than half the target levels. Clausen and Yang (2005) found that the 0.043 wt/wt% of voriconazole, which shows more efficacy against mold than tebuconazole, was needed to inhibit mold growth on unseasoned southern pine. This suggests that 0.024 wt/wt% tebuconazole was inadequate in this application.

Mold growth was much lower on panels containing DCOI alone or with copper compounds throughout the 8-wk test. Boards treated with DCOI alone had a rating of 2.5 after 2 wk compared with the controls (400 s). DCOI also showed reasonable efficacy against mold growth as a cobiocide. Addition of DCOI to panels with CC 1 and CC 2 resulted in ratings below 4, even after 6-wk exposure. Actual DCOI loadings were one-half of the target levels, suggesting that resistance to mold growth would have been improved had target levels been met. DCOI is subject to degradation at high pH levels (Morrell 2004), but the two copper complexes did not appear to completely diminish moldicidal efficacy.

CONCLUSIONS

Nearly all preservative treatment systems except MCOH or DCOI alone were effective against brown- or white-rot fungi at one or more target loadings. Most systems had little effect on surface mold growth on the panels. Tebuconazole initially limited mold growth, but mold growth was similar to that on controls after 3 wk. DCOI significantly improved resistance to mold growth compared with untreated panels. Copper-based preservatives in conjunction with DCOI appeared to provide the best protection for aspen OSB. Actual loading levels of most treatments used in this study were well below target levels, which limited the effectiveness of the treatment. Improved treatment delivery systems for strandboard applications are needed.

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