Test method for assessing resistance of pine lumber and waferboard to mold

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Abstract

Methods are needed to evaluate the ability of framing lumber and composite construction materials to withstand mold growth when they are exposed to rain between manufacture and installation. A laboratory-controlled rain chamber was developed to expose biocide-treated specimens of pine lumber and waferboard to bi-weekly wetting followed by re-inoculation with test fungi. In the rain chamber mold test, an experimental biocide, which contained propiconazole, performed as well as the positive control, which contained iodo carbamate and didecyl dimethyl ammonium chloride. However, results from the rain chamber test method did not correlate with results from a standard ASTM laboratory mold test for the experimental biocide. In additional tests of kiln-dried, rewetted, and unseasoned pine, untreated specimens showed heavy mold growth after 7 days regardless of their original moisture content. Results for a matching set of specimens dip-treated in disodium octaborate tetrahydrate (DOT) revealed that rewetted and unseasoned specimens supported mold growth equally well after a 4-week incubation in the laboratory mold test, while DOT-treated kiln-dried specimens moderately inhibited mold growth. These specimens likely retained more treatment than did their wet counterparts. Ideally, waferboard and kiln-dried pine should be rewetted to adequately support mold growth in the standard laboratory mold test. The rain chamber mold test provided prolonged conditions of high moisture, even for kiln-dried pine and waferboard specimens, and mimicked exposure of construction materials to moisture during storage.

Contractors, homeowners, and manufacturers of building materials are concerned about the incidence of mold on construction materials. During storage between manufacture and installation, building materials are often exposed to occasional moisture, most often due to rainfall. When mold growth is cited as a problem in a dwelling, assigning culpability is virtually impossible. Homeowners contact contractors who contact distributors who finally contact manufacturers. In reality, once a product is shipped for distribution, the manufacturer loses control of the storage conditions. Likewise, the distributor cannot control storage conditions or construction delays at a construction site. Methods are needed to evaluate the ability of framing lumber and composite sheathing materials to withstand mold growth when they are unintentionally exposed to rain between manufacture and installation. Surface treatments, such as dipping or spraying with biocides, need to be developed to protect construction materials during storage and transit. Ideally, such treatments would also provide long-term protection of building materials beyond installation. Preliminary studies by Clausen and Yang (2003, 2004) showed that fungicides used in alternative applications, such as pharmaceutical, agricultural, and food preservation, as well as plant extractives can protect wood from the establishment of mold.

The objectives of this study were threefold:

1. to develop a laboratory method to mimic occasional wetting of wood construction materials,
2. to compare rewetted southern pine with unseasoned southern pine in a standard laboratory mold test, and
3. to evaluate two experimental biocide surface treatments by both methods.

Materials and methods

Test fungi

Aspergillus niger 2.242, *Penicillium chrysogenum* PH02, and *Trichoderma viride* ATCC 20476 were maintained on 2 percent malt agar (Difco, Detroit, MI). Spore inocula were pre-

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pared according to ASTM D 4445-91 (ASTM 1998) by washing the surface of individual 2-week-old cultures of each fungus with 10 mL sterile deionized (DI) water and transferring the liquid spore suspension into a spray bottle. Each spore suspension was diluted to 100 mL with sterile DI water. The spray bottle was adjusted to deliver 1 mL inoculum per spray containing approximately 10^7 spores/mL.

Test specimens

Kiln-dried southern pine studs (3.6 by 8.8 cm) were cut into specimens measuring 7 by 20 mm in cross section by 7 cm long and conditioned at 70 percent relative humidity (RH). Unseasoned wood specimens (7 by 20 mm cross section by 7 cm long) were cut from southern pine mill ends from a Mississippi sawmill and stored at 0°C. Southern pine waferboard (11 mm thick) was cut into 20-mm cross-section by 7-cm-long specimens and conditioned at 70 percent RH.

Test chemicals

Three test chemicals were used: biocide A, biocide B, and disodium octaborate tetrahydrate (DOT). Biocide A, which consisted of 21 percent aluminum nitrate nonahydrate, 25 percent dimethylcocoamine, 11 percent polyaluminum chloride, and 1 percent propiconazole (1-[[2-(2,4-dichlorophenyl)-4-propyl-1,3-dioxolan-2-yl]-methyl]-1H-1,2,4-triazole), was tested at 2 percent wt/v. Biocide B, which consisted of 21 percent aluminum nitrate nonahydrate, 25 percent dimethylcocoamine, 11 percent polyaluminum chloride, and 2 percent boric acid (National Boraxx, Cleveland, OH), was tested at 2 percent wt/v. The DOT (U.S. Borax Inc., Valencia, CA) treatment was tested at 15 percent wt/v.

Experimental rain chamber mold method

Five specimens each of kiln-dried pine and waferboard were dip-treated for 15 seconds in biocide A and B. Specimens dipped in DI water served as negative controls and specimens dipped in 1 percent of a solution containing 7.6 percent 3-iodo-2-propynyl butyl carbamate and 64.8 percent didecyl dimethyl ammonium chloride served as positive controls. Dip-treated specimens were held overnight in a closed container before being air-dried for 7 days. Groups of five specimens for each treatment were placed in a test apparatus consisting of a lidded aluminum tray (30.5 by 25.4 by 11.4 cm) with six drainage holes in the bottom that were covered with four layers of absorbent paper and a polyethylene mesh screen to elevate the test specimens. Each apparatus was exposed to 2 inches (50 mm) of rain (hereafter called a "rain event") in a pre-calibrated laboratory-controlled rain chamber, followed by spray inoculation with 2 mL of an individual mold spore suspension containing *Trichoderma viride*, *Penicillium chrysogenum*, or *Aspergillus niger*. Trays were covered with aluminum foil lids and incubated at 27°C, 70 percent RH. Specimens were rated for percentage of surface mold coverage at 2-week intervals. Following each rating period, specimens were exposed to a rain event and re-inoculated with mold spores. Biweekly ratings continued for 20 weeks, and individual treatments ceased when specimens failed to substantially resist growth of test fungi.

Standard laboratory mold method

Waferboard specimens were rewetted in DI water under 172.4 kPa for 20 minutes. Five specimens each of waferboard and unseasoned southern pine were dip-treated for 15 seconds in biocide A. Average moisture content (MC) of the unseasoned pine was 48 percent by weight (n = 3). Specimens dipped in DI water served as a negative control. Specimens were held for 24 hours in a covered test apparatus, according to a modification of ASTM standard test method D 4445-91 (ASTM 1998). Each test apparatus was assembled by placing four layers of blotting paper in a sterile disposable petri dish (150 by 25 mm) (B-D Falcon, Los Angeles, CA). A polyethylene mesh spacer was placed on top of the filter paper stack, which had been saturated with 30 mL DI water. Each apparatus contained five specimens treated with a single concentration of test solution per test fungus. Controls consisted of untreated specimens dipped in DI water. Specimens were sprayed with 1 mL of fungal spore inoculum and petri dish lids were replaced. Inoculated test apparatuses were sealed in polyethylene bags to prevent drying and incubated at 27°C and 70 percent RH.

An additional test was conducted to evaluate the effect of using rewetted wood in the ASTM method, which was standardized for unseasoned wood. Five specimens each of kiln-dried, rewetted (as previously described), and unseasoned southern pine were dipped for 15 seconds in 15 percent DOT. A matching set of samples were dipped in DI water. Specimens were prepared and tested (as previously described) with one test fungus, *Aspergillus niger*. Specimens were evaluated weekly for 4 weeks.

Mold rating system

Specimens were examined periodically for mold growth and rated from 0 to 5, with 0 equaling no visible growth and 5 equaling 100 percent coverage of all surfaces with the test fungus. When the average of five ratings exceeded 50 percent of the average rating of the negative controls, the test was discontinued for that group and the number of weeks-to-failure was recorded. For example, for ratings of 1, 3, 3, 5, 5, the average rating would be 3.4, which equals 68 percent of the average rating of the negative control (5.0).

Results and discussion

Table 1 shows the number of weeks until specimens in the rain chamber test method failed to resist mold growth. Untreated negative control specimens predictably failed to inhibit test fungi in 2 to 6 weeks. Positive controls remained protected from growth by test fungi for 20 weeks or longer under the conditions of this test. In pine specimens, biocide A protected against *T. viride* for 20 weeks, *P. chrysogenum* for 14 weeks, and *A. niger* for 12 weeks. Biocide A performed best on waferboard, with all of the specimens showing continued protection beyond 20 weeks. It was difficult to macroscopically rate waferboard specimens because of color variations in the product. Better methods need to be devised for evaluating composite products for mold growth.

Results of the ASTM standard method for testing mold resistance on unseasoned pine and rewetted waferboard showed that biocide A repeatedly failed to inhibit *A. niger*, *P. chrysogenum*, and *T. viride* after just 6 days of incubation (results not shown). Note that unless waferboard specimens were rewetted prior to testing in the ASTM standard test, they absorbed the moisture intended to keep the test apparatus at 100 percent RH for the duration of the test, resulting in low RH and poor spore germination.

Although the ASTM and rain chamber test methods varied in initial sample moisture, it seemed a reasonable assumption that rapid moisture equilibration would occur in all specimens within days to weeks. To help answer that question, additional tests were conducted with disodium octaborate tetrahydrate (DOT) treatment on kiln-dried, rewetted, and unseasoned pine by the ASTM method. Mold ratings for both DOT-treated unseasoned and rewetted specimens were comparable, with a failure to inhibit mold following the 4-week incubation. The DOT-treated kiln-dried specimens moderately inhibited mold growth even after 4 weeks, presumably because of higher chemical uptake (**Table 2**). Chemical retentions for aqueous biocides have been shown to be approximately 6 percent higher in kiln-dried pine compared with unseasoned pine following a 15-second dip treatment (Clausen and Yang 2005).

Table 1. — Time before establishment of mold on kiln-dried southern pine and waferboard subjected to bi-weekly rain events and re-inoculation with test fungi.

	Time to failure (weeks) of pine and waferboard subjected to various fungi					
	T. viride		*P. chrysogenum*		*A. niger*	
Treatment	Pine	Waferboard	Pine	Waferboard	Pine	Waferboard
Control	4	4	6	2	2	2
Positive control	>20	>20	20	20	20	>20
Biocide A	20	>20	14	>20	12	>20
Biocide B	2	2	22	2	2	2

Biocide efficacy is routinely tested on unseasoned pine for several reasons. First, building with unseasoned lumber is an accepted practice in some regions of the United States. Second, laboratory tests attempt to mimic real construction scenarios where building materials rarely remain dry throughout the entire construction process. Third, if a biocide can protect unseasoned wood from mold growth, then it should have equal or greater success in protecting kiln-dried material from mold growth. Testing kiln-dried pine and waferboard under the conditions of repeated wetting and re-inoculation attempted to mimic occasional wetting of building materials during lumberyard storage and the construction process. Biocide depletion was not determined, although each rain event would have been expected to deplete the biocide to some extent. In the rain chamber, spores were washed from the surface of specimens with small amounts of mold growth, but specimens were continually challenged by re-inoculation following each rain event, as would naturally occur in a warm, humid outdoor environment. The significant differences between the two methods evaluated in this study were:

a. the constant 100 percent humidity in the polyethylene-sealed ASTM test method as opposed to the "breathable" rain chamber test method,

b. the single inoculation of mold spores in the ASTM test vs. repeated inoculation in the rain chamber test that resulted in 10 times more inoculum over the course of the study, and

c. the bi-weekly rain events in the rain chamber method, which ensured that specimens were exposed to repeated wetting, although covered drain holes allowed for some drying between rain events.

Table 2. — Mold growth on kiln-dried, rewetted, and unseasoned southern pine challenged with A. niger in standard ASTM mold test

		Average[a] mold growth rating at various times (days) post-inoculation			
Specimen	Treatment	7	14	21	28
Kiln-dried	DOT	0	0	1.6	2.4
	Untreated	5	5	5	5
Rewetted	DOT	1.2	1	3.6	4.2
	Untreated	5	5	5	5
Unseasoned	DOT	1	0.8	2.2	4.2
	Untreated	5	5	5	5

[a] $n = 5$.

Conclusions

Biocide A performed well in the experimental rain chamber mold test that subjected kiln-dried pine and waferboard specimens to bi-weekly "rain events" and re-inoculation with test fungi. However, the same biocide formulation repeatedly failed to inhibit test fungi after 1 week in the ASTM standard test for controlling mold on unseasoned lumber. A comparison of kiln-dried, rewetted, and unseasoned wood tested by the ASTM method showed that all of the untreated specimens supported heavy mold growth after 7 days of incubation, indicating that rapid moisture equilibration occurred in all specimens. Results for a matching set of specimens dip-treated with DOT showed that rewetted and unseasoned pine had comparable mold growth ratings, probably due to leaching of DOT after 4 weeks of incubation. The DOT-treated kiln-dried material moderately inhibited mold growth. Higher chemical retentions of kiln-dried southern pine dip-treated with aqueous biocides may account for this difference. The rain chamber mold test was designed to expose kiln-dried wood to repeated wet and dry cycles during storage. Although the rain events ensured high moisture levels throughout the test period, repeated wetting may have leached soluble treatments. Both the ASTM test and the rain chamber test are laboratory methods that mimic different conditions, and it is not clear whether either test is more realistic for conditions in the field. Comparing and contrasting laboratory mold test methods is advisable when evaluating new biocide formulations.

Literature cited

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