Ability of bleach and other biocide treatments to remove and prevent mold growth on Douglas-fir lumber

Adam M. Taylor
Camille M. Freitag
Jeffrey J. Morrell*

Abstract

Molds are an increasingly important issue for all building materials, including wood. While washing with bleach is a commonly recommended method for removing molds, and the associated discolorations, there is surprisingly little information on the effectiveness of this treatment. The ability of mold removal treatments to brighten wood and eliminate fungi was assessed on Douglas-fir *(Pseudotsuga menziesii)* sapwood lumber heavily colonized with mold and sapstain fungi. The boards were subjected to different washing treatments: wiping with bleach solution, wiping with water, and a no-wash control. Samples were evaluated visually for changes in mold appearance and then fungi were isolated from the surface of the wood. Replicates from the various wash treatments were further treated with three biocide formulations. The effect of the mold control treatments on visual appearance and fungal diversity was assessed 1 month after treatment. Increasing bleach concentrations from 2.5 up to 20 percent solution had no effect on the appearance of the wood following the wash treatment, nor did such treatments completely eliminate fungi from the wood surface. The chemical mold prevention treatments tested were not effective in sterilizing the wood, nor did they improve the visual appearance.

From the moment it is cut in the forest until it dries to moisture levels below 20 percent (wt./wt.), wood remains susceptible to colonization by a variety of molds, sapstains, and decay fungi (Dowding 1970, Kaarik 1980). For many years, lumber producers limited the risk of fungal attack by managing production to avoid long storage periods, spraying or ponding stored logs to raise moisture levels above those suitable for fungal growth, kiln-drying, or applying fungicides to sawn lumber in topical treatments (Scheffer and Lindgren 1940). These latter treatments were primarily prophylactic, and designed to protect the wood only during the time between sawing and when moisture contents were reduced to below 20 percent.

The decision by the U.S. Environmental Protection Agency in the late 1980s to restrict the use of sodium pentachlorophenates, coupled with increasing concerns over worker exposure to antistain chemicals, led to a gradual decline in anti-sapstain chemical usage (R.C.Anderson et al. 2002). This decline was accompanied by increased kiln capacity in the southern United States, but many mills in the West elected to eliminate treatment while continuing to provide green material. This approach worked well as long as domestic customers were willing to accept moldy, stained wood. Recently, however, several high visibility court cases have resulted in substantial settlements because of mold on building materials, including wood (Robbins and Morrell 2002). These actions have renewed interest in prophylactic anti-stain treatments. There are an array of effective, less toxic chemicals for this purpose, but these systems are not designed for application in structures (Morrell et al. 2002).

At the same time, there has been increased interest in methods for removing fungal discoloration on wood already installed, as well as in treatments to limit fungal growth under these conditions.

The authors are, respectively, Graduate Research Assistant, Senior Research Assistant, and Professor, Dept. of Wood Science and Engineering, Oregon State Univ., 119 Richardson Hall, Corvallis, OR 97331. This paper was received for publication in October 2002. Article No. 9557.
*Forest Products Society Member.

Forest Prod. J. 54(4):45-49.

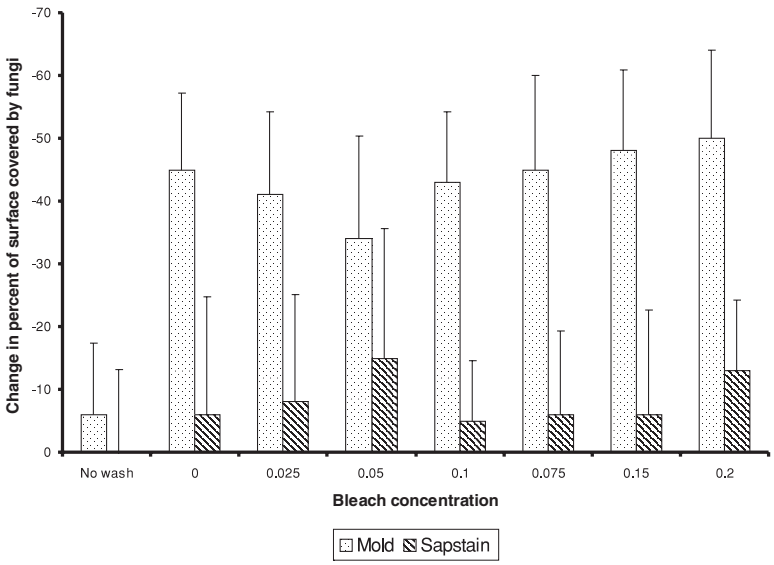

Figure 1. — Ability of water or bleach washes to reduce the degree of surface mold coverage or internal sapstain on Douglas-fir sapwood boards. Bars represent two standard errors.

While wood can be colonized by an array of organisms (Hawksworth 1991), the primary concern of many has been the "toxic mold" *Stachybotrys chartarum* (Johanning et al. 1996, Fung et al. 1998, Hodgson et al. 1998, Daggett et al. 1999, B. Anderson et al. 2002). This fungus does not appear to be associated with freshly sawn Douglas-fir lumber (Kang and Morrell 2000), but it is primarily found in cellulose-based materials (Ellis 1971).

A commonly recommended treatment for mold removal is to flood the wood surface with a dilute solution of sodium hypochlorite (bleach), and then brush the wood to dislodge spores and hyphal fragments (Oregon Dept. of Human Services 2002). Bleach is a potent disinfectant (Russell et al. 1982), but there is little data supporting its effectiveness for this application. Similarly, a number of compounds are marketed that claim to eliminate mold growth on wood, but there is little to support these claims.

In this report, we describe tests to evaluate the ability of bleach and/or various treatments to improve the visual appearance of moldy wood and reduce subsequent fungal recolonization on the wood surface.

Materials and methods

Heavily stained Douglas-fir sapwood (*Pseudotsuga menziesii* (Mirbel) Franco) boards (19 mm by 133 mm by various lengths) were obtained from a local lumberyard. The boards had not received any prior fungicidal treatment, and had been solid piled in storage. The boards were cut into 89-mm-long sections that were randomly allocated to 20 treatment groups of 10 sections each.

Wash treatments

The surface condition of each board was assessed visually using a scale from 0 (no evidence of discoloration) to 100 (complete surface discoloration) for both surface mold and sapstain. All visual assessments were conducted by the same person. The boards were then treated with water or bleach diluted with water to 2.5, 5.0, 7.5, 10.0, 15.0, or 20 percent (vol./vol.). Additional sets of boards were left untreated. In an effort to mimic normal practice with wood in vertical exposures, the solution was wiped on the surface with a sponge, allowed to stand for 30 seconds, and then rinsed off by dunking the piece in clean water. The boards were allowed to dry for 20 to 30 minutes, then reassessed for surface condition as described above. Each treatment was replicated on 10 board sections. Following visual assessment, the ability of each treatment to kill surface fungi was assessed by pressing a 25-mm-long section of 12-mm-wide clear plastic tape (Post-it™ tape "flags") on the wood surface. The tape sections then were placed, face down, on 1 percent malt extract agar in plastic petri dishes, incubated under ambient lab conditions (20° to 23°C), and observed for evidence of fungal growth. Fungi were identified to genus using the appropriate taxonomic keys (Ellis 1971, Barnett and Hunter 1972, Ellis 1976, Wang and Zabel 1990, Webster 1993). The total number of isolations/board, as well as the number of isolations of each genus, were noted for each treatment group.

Topical prevention treatments

The potential of three supplemental surface treatments to limit fungal growth was examined on board sections that had received no previous wash treatment, on boards that had been previously washed with tap water, and on boards that had been washed with a 10 percent bleach solution as described previously.

Boards to be treated with water-based 10 percent disodium octaborate tetrahydrate (DOT) (Timbor, U.S. Borax, Valencia, California) or 10 percent DOT plus ethylene glycol (Boracare, NISUS Corp., Nashville, Tennessee) were immersed in the treatment solution for 5 seconds, then allowed to dry for 15 minutes. The 2 percent didecyldimethylammonium chloride (DDAC) (Anti-Growth, Glessner Sales Incorporated, Bend, Oregon) treatment was applied by wiping the surface with a saturated sponge.

Following treatment, the blocks were visually assessed, and then placed in plastic bags and incubated at 32°C and 90 percent relative humidity. At the end of 4 weeks of incubation, the blocks were again visually evaluated for discoloration, and the degree of microbial colonization was assessed using the previously described tape method.

Results and discussion

Bleach treatments

All of the surface wash treatments reduced the discoloration due to molds, including the water wash **(Fig. 1)**; however, there was little or no difference between the treatments. The wash treatments, including those containing bleach, had little effect on sapstain, reducing the degree of discoloration by only 5 to 15 percent. These low values probably reflect the relatively short residence time that the bleach was in contact with the wood and the difficulty in degrading the complex melanins that give

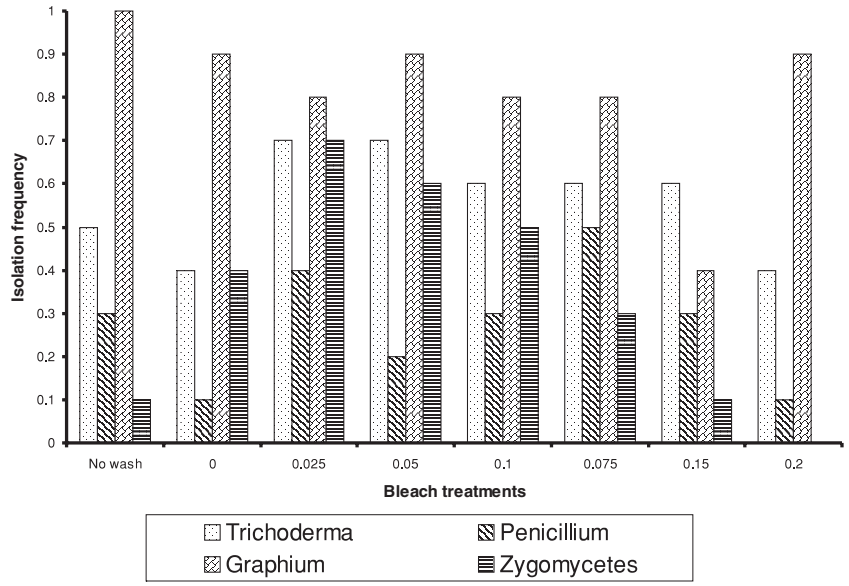

Figure 2. — Isolation frequency of selected fungi from Douglas-fir sapwood boards washed with water or increasing concentrations of bleach in comparison with unwashed control boards.

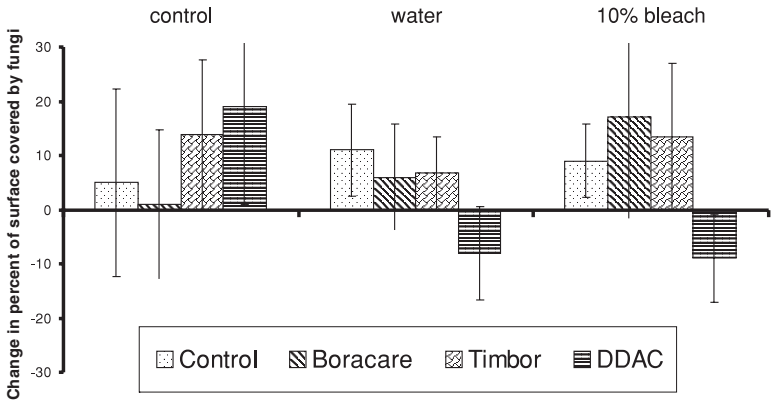

Figure 3. — Change in degree of surface discoloration of Douglas-fir sapwood boards that were unwashed, water washed, or bleached, then treated with selected topical treatments and incubated for 28 days at 32°C.

the hyphae their color (Zink and Fengel 1988).

Fungal isolations were categorized on the basis of frequency from a given set of boards for a given treatment. The majority of fungi isolated were members of the genera *Trichoderma*, *Penicillium*, or *Graphium*. The abundance of these genera on wood is typical of Douglas-fir sapwood (Kang and Morrell 2000), and reflects the ability of these fungi to produce prodigious numbers of spores. In addition, *Zygomycetes* were isolated from many samples, although these fungi were not identified to genus.

Zygomycetes were infrequently isolated from unwashed boards, but their frequency increased on boards washed with water or 2.5 percent bleach **(Fig. 2)**. Isolation levels then steadily declined with increased bleach concentration, and no *Zygomycetes* were isolated from boards treated with 20 percent bleach. Some of the wash treatments may have altered the wood environment to favor growth by the *Zygomycetes* already present on or in the wood. Isolations of *Trichoderma* species varied slightly with the various treatments, but the differences were not consistent. *Penicillium* species also varied inconsistently with bleach concentration. *Graphium* species were isolated from all unwashed boards, and isolation levels declined only slightly in all but one of the wash treatments. The exception was the 15 percent bleach treatment; however, we consider this result to be anomalous since isolation levels were high for the 7.5 and 20 percent bleach treatments. The high incidence of *Graphium* isolations reflects the adaptation of this genus for wood, as well as its ability to produce massive amounts of sticky spores.

The isolation frequencies of the various fungi do not imply that the boards were covered with spores or hyphal fragments; however, the results show that viable fungal propagules remain on the wood surface following bleach treatment. Some airborne spores also may have landed on the boards as they were drying; however, regardless of the origin of the fungi, failure to alter the conditions on the wood surface, primarily through drying, will invariably lead to regrowth of these fungi.

Topical prevention treatments

Most of the boards receiving topical treatments experienced modest increases in the degree of fungal discoloration after the 28-day incubation period (**Fig. 3**). It is important to remember that these boards were heavily discolored prior to treatment, so further large changes in discoloration were unlikely. Boards that had been washed with water or 10 percent bleach prior to treatment tended to be more heavily discolored when they were left untreated, or treated with either boron compound, while their appearance tended to improve slightly when DDAC was applied. Water and bleach washes tended to reduce surface discoloration by 40 to 50 percent (**Fig. 1**), but obviously they did not kill all the spores on the wood surface; it is clear that the fungi remaining on the wood

Table 1. — Isolation frequency of various fungal genera from unwashed, water-washed, or bleached Douglas-fir sapwood boards 28 days after the application of selected topical treatment.

Prevention treatment	Pretreatment	*Trichoderma*	*Penicillium*	*Graphium*	*Aspergillis*
		(%)			
Control	Control	50	10	80	0
	Water	70	10	100	10
	10% bleach	90	0	100	0
Boracare	Control	70	50	0	70
	Water	80	40	0	70
	10% bleach	90	0	10	20
Timbor	Control	80	0	10	0
	Water	70	10	10	10
	10% bleach	100	10	10	0
DDAC	Control	20	30	40	10
	Water	30	20	50	30
	10% bleach	50	40	10	10

surface after treatment were capable of continued growth and discoloration when the wood was stored under ideal growth conditions. The DDAC treatment appeared best able to inhibit further discoloration, a finding that supports its frequent use as a component of anti-stain formulations.

Isolation frequencies for *Trichoderma* species were generally high for all treatments (>80% of boards), but were highest on control (no prevention treatment) and Boracare-treated/previously bleached boards (**Table 1**).

Penicillium species were far less abundant than *Trichoderma* in general (**Table 1**), and were absent from unwashed and bleached boards treated with Timbor, and bleached boards left untreated or treated with Boracare. DDAC had little effect on *Penicillium* isolation frequency, regardless of the pretreatment.

Although they were infrequently isolated in the initial wash treatments test, *Aspergillus* species were isolated from 60 percent of the control or water-washed boards treated with Boracare (**Table 1**). They were also isolated at low levels (<30%) from water-washed boards in all four treatment groups, as well as from unwashed DDAC-treated boards. These results suggest that incubation conditions (hot and humid) may have favored the growth of these species.

Graphium species were isolated from all unwashed, water-washed, or bleached boards that did not receive a subsequent treatment (**Table 1**). Isolation levels of these fungi declined sharply from boards receiving topical treatments. Isolation levels were highest on boards treated with DDAC, ranging from 15 to 50 percent of the boards. No *Graphium* species were isolated from the unwashed or water-washed boards treated with Boracare, while 10 percent of the previously bleached boards treated with this chemical yielded such fungi. *Graphium* species were isolated from each of the Timbor treatments, but the levels were low (<20% of the boards). The dramatic decline in *Graphium* frequency following topical treatments suggests that these sapstain fungi are more easily controlled than the more abundant mold fungi.

Implications

While bleach is often recommended for remediation of surface mold on wood, our results illustrate that the treatment does not eliminate the surface microflora. As a result, an important component of remediation must be drying to moisture levels below 20 percent (the generally accepted level for inhibiting growth of fungi on wood) (Zabel and Morrell 1992). In the absence of drying, some fungi clearly survive the treatment and may re-colonize the surface.

The application of topical treatments also produced variable results. None of the treatments inhibited all of the fungi present. These treatments were selected because they are being touted as mold treatments and because of their relatively low toxicity profiles that would allow their use without a pesticide applicator license. However, it is clear that these treatments lack the broad spectrum activity required to reduce the activity of such a diverse microflora. Exploration of mixtures of these materials is advisable.

The results highlight the difficulty of complete removal of surface colonization by fungi and emphasize the importance of prevention, either by kiln-drying or by the application of topical fungicides soon after sawing.

Literature cited

Anderson, B., K.F. Nielson, and B.B. Jarvis. 2002. Characterization of *Stachybotrys* from water-damaged buildings based on morphology, growth, and metabolite production. Mycologia 94(3):392-403.

Anderson, R.C., E. Hansen, and J.J. Morrell. 2002. Use of anti-stain chemical treatments by the western U.S. softwood lumber industry, 1999. Forest Prod. J. 52(4):69-71.

Barnett, H.L. and B.B. Hunter. 1972. Illustrated Genera of Imperfect Fungi. 3rd ed. Burgess Publishing Company, Minneapolis, MN. 241 pp.

Daggett, D.A., M. Chamberlain, and W. Smith. 2001. Effects of exterior decay and mold on indoor mold and air quality. *In*: Proc. 2nd Annual Conference on Durability and Disaster Mitigation. Forest Prod. Soc., Madison, WI. pp. 79-82.

Dowding, P. 1970. Colonization of freshly bared pine sapwood surfaces by staining fungi. Transactions British Mycological Soc. 55(3):399-412.

Ellis, M.B. 1971. Dematiaceous hyphomycetes. Commonwealth Mycological Inst., Kew, UK. 608 pp.

_____. 1976. More dematiaceous hyphomycetes. Commonwealth Mycological Inst., Kew, UK. 507 pp.

Fung, F., R. Clark, and S. Williams. 1998. *Stachybotrys*, a mycotoxin-producing fungus of increasing toxicologic importance. Clinical Toxicology 36(1&2):79-86.

Hawksworth, D.L. 1991. The fungal dimension of biodiversity: Magnitude, significance, and conservation. Mycological Research 95(6): 641-655.

Hodgson, M.J., P. Morey, W-Y. Leung, L. Morrow, D. Miller, B.B. Jarvis, H. Robbins, J.F. Halsey, and E. Storey. 1998. Building-associated pulmonary disease from exposure to *Stachybotrys chartarum* and *Aspergillus versicolor*. J. of Occupational and Environmental Medicine 40(3):241-249.

Johanning, E., R. Biagini, D. Hull, P. Morey, B. Jarvis, and P. Landsbergis. 1996. Health and immunology study following exposure to toxigenic fungi (*Stachybotrys chartarum*) in a

water-damaged office environment. Inter. Archives of Occupational and Environmental Health 68:207-218.

Kaarik, A. 1980. Fungi causing sapstain in wood. IRG/WP/199. Inter. Research Group on Wood Preservation, Stockholm, Sweden. 112 pp.

Kang, S.M. and J.J. Morrell. 2000. Fungal colonization of Douglas-fir sapwood lumber. Mycologia 92(4):609-615.

Morrell, J.J., C.S. Love, and C.M. Freitag. 2002. Preventing discoloration of unseasoned hem-fir and Douglas-fir lumber with selected fungicide formulations. Forest Prod. J. 52(2): 53-61.

Oregon Department of Human Services. 2002. Fact Sheet: About household mold and mildews. www.ohd.hr.state.or.us/esc/docs/mold.htm. Accessed Aug. 29, 2002.

Robbins, C. and J.J. Morrell. 2002. Mold, housing, and wood. Western Wood Prod. Assoc., Portland, OR. 11 pp.

Russell, A.D., W.B. Hugo, and G.A.J. Ayliffe, eds. 1982. Principles and Practice of Disinfection, Preservation and Sterilization. Blackwell Scientific Publications, Boston, MA. 653 pp.

Scheffer, T.C. and R.M. Lindgren. 1940. Stains of sapwood products and their control. Tech. Bull. 714. USDA, Washington, DC.

Wang, C.J.K. and R.A. Zabel. 1990. Identification manual for fungi from utility poles in the eastern United States. Allen Press, Inc., Lawrence, KS. 365 pp.

Webster, J. 1993. Introduction to Fungi. 2nd ed. Cambridge Univ. Press, Cambridge, UK. 669 pp.

Zabel, R.A. and J.J. Morrell. 1992. Wood Microbiology: Decay and its Prevention. Academic Press, San Diego, CA. 474 pp.

Zink, P. and D. Fengel. 1988. Studies on the coloring matter of blue-stain fungi. Part 1. General characterization and the associated compounds. Holzforschung 42(4):217-220.