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Prevention of Mold Growth on CCA-treated Radiata Pine Lumber by Incorporation of Moldicide into the CCA Solution*1

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ABSTRACT

Surface mold fungi growing on CCA-treated wood could be inhibited effectively by the incorporation of moldicide into treating solution. In this study, moldicides compatible with the CCA solutions from various commercial moldicides were screened, and then their optimum concentrations for controlling surface mold on CCA-treated radiata pine sapwood were examined through both the laboratory and the field trials. Among nine commercial moldicdes tested, two substituted isothiazolinones, moldicide A containing 2-n-octyl-4-isothiazoline-3-one and moldicide B containing 5-chloro-2-methyl-4-isothiazolin-3-one and 2-methyl-4-isothiazolin-3-one, were chemically compatible with CCA solution. The optimum concentration to be incorporated into 2% CCA treating solution was determined to be 0.001% for moldicide A and 0.003% for moldicide B.

Keywords : CCA, surface mold, prevention, moldicides, radiata pine

1. INTRODUCTION

Waterborne preservative treated wood products are very susceptible to surface mold if solid-piled when wet, particularly during warmer weather. Mold problem with CCA alternatives treated wood were much severe than that with CCA treated wood (Harris 2003). Preventing mold development will be essential for the production of clean treated wood, thereby reducing the increased losses in revenue. This mold problem can be prevented by rapid kiln drying the treated wood below 20% moisture content, incorporation of moldicides (or mold inhibitors) into the treatment solutions or post treatment dipping of treated wood into the modicide solutions (Morrell 2004). Although kiln drying treated wood would reduce the risk of mold, kiln drying is not a feasible approach to mold control on an industrial scale, mainly due to the added drying costs to the finished products. Post treatment chemical application has also serious drawbacks. This approach requires an additional processing step and also creates the po-

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Table 1. Compatibility test results of various moldicides with 2% CCA solution

Moldicide	Chemical name	a.i.[*1] (%)	Compatibility with CCA
A	2-n-octyl-4-isothiazoline-3-one	4	compatible
B	5-chloro-2-methyl-4-isothiazolin-3-one 2-methyl-4-isothiazolin-3-one	10～12 3～5	compatible
C	Chlorothalonil Carbindazim	40～45 5～10	noncompatible
D	4,5-dichloro-2-n-octyl-4-isothiazolin-3-one	24.5	noncompatible
E	Didecyldimethylammonium chloride	50	noncompatible
F	Sodium ortho-phenylphenate tetrahydrate	32.6	noncompatible
G	Didecyldinethylammonium chloride Propiconazole	46.25 4.9	noncompatible
H	2-(thiecyanomethylthio) benzothiazole	30	noncompatible
I	Didecyldimethylammonium chloride 3-iodo-2-propynyl butyl carbamate	64.34 7.55	noncompatible

[*1] Active ingredient

tential for solution interactions that might lead to sludging. Therefore, incorporation of moldicides into the preservative solution should be the best solution to the mold problem.

Currently, one imported moldicide (substituted isothiazolinones) is being exclusively used in domestic pressure treatment plants. The majority of treaters employed higher concentrations of this moldicide in their treatment solutions. While this approach will reduce the risk of mold development, it has several drawbacks such as worker's health hazards and increased treatment costs. Optimum concentration of this moldicide, therefore, should be identified for solving above-mentioned drawbacks.

This report screens moldicides compatible with the CCA solutions from various commercial moldicides including the moldicide currently used in treatment plants, and identifies optimum concentration of screened moldicides for controlling surface mold. Development of preventive techniques of mold problem with CCA alternatives treated wood is in progress and the results will be reported later.

2. MATERIALS and METHODS

2.1. Selection of Compatible Moldicides with CCA

A primary investigation to determine which moldicides are compatible with CCA was conducted by placing equal volume of an undiluted moldicide solution and 2% CCA solution in a vial. The vial was agitated vigorously, and the solutions that did not exhibit phase separation or precipitation were judged to be compatible. In total, nine commercial moldicides, including one moldicide currently used in treatment plant, were tested (Table 1).

2.2. Laboratory Trials

The accelerated 8-week laboratory tests were performed to identify proper solution concentrations of selected moldicides for the incorporation into 2% CCA solution to be used in the field trials. Moldicides were tested a greater range of solution concentrations than those recommended by their suppliers.

The ability of selected moldicides to control surface mold by incorporation into the CCA solution was assessed by standard method described in ASTM D4445-91 (ASTM 1996) with some modifications. Air-dried radiata pine (*Pinus radiata* D. Don) sapwood specimens (7 mm by 20 mm in cross section and 70 mm long) were vacuum-impregnated with 2% CCA type C solution mixed with various concentrations of moldicides. Five concentrations of moldicides were formulated for each moldicide. Specimens treated with distilled water and 2% CCA solution served as controls.

After treatment, the steam-sterilized specimens were placed on plastic mesh over three layers of absorbent paper towel in an aluminum pan to maintain high humidity during the test period, and sprayed to runoff with a fungal inoculum cocktail prepared by combining the inoculum for nine species of mold fungi (*Aureobasidium pullulans* KUC3002, *Cladosporium cladosporioides* KUC3027, *Cladosporium oxysporum* KUC 3006, *Cladosporium sphaerospermum* KUC3009, *Hyalodendron* sp. KUC3057, *Phialophora melinii*-like KUC3011, *Phialophora* sp. KUC3032, *Phoma glomerata* KUC3007, and *Phoma herbarum* KUC3005). These test fungi were isolated from CCA treated radiata pine lumber stored in solid piles during summer rainy season in the storage yard of a commercial treatment plant (Kang *et al.* 2006). Although there were remarkable differences in the degree of discoloration, all the tested fungi discolored CCA treated radiata pine sapwood specimens (Kang 2006). The aluminum pans were covered with lids and put into plastic bags to retain moisture.

After 2, 4, 6 and 8 weeks of incubation at 27°C, the fungal discoloration on the upper surface of specimens was visually assessed to nearest 5% using a scale from 0 (no discoloration) to 100% (complete discoloration). The degree of discoloration was assessed as a percentage of the area of fungal discoloration over the area of the entire upper surface.

2.3. Field Trials

Air-dried radiata pine sapwood boards (30 by 90 mm in cross section and 900 mm long), free of visible fungal discoloration, were pressure-treated with 2% CCA type C solution in combination with various concentrations of moldicide solutions. Five concentrations of moldicides were formulated for each moldicide. Boards treated with 2% CCA solution served as controls.

After treatment, treated boards were block-stacked (four boards high and four boards wide) with best face for testing upturned on a pair of bearer on the ground. Treated packets were stored outdoor at a commercial treatment plant, and their upper surface was covered with polyethylene film to prevent wash out of treatment solution by rainfall. The tests were commenced at the middle of July, and completed by early September 2005. Table 2 shows the mean temperature, mean relative humidity and total rainfall of test sites during field trials.

After 2, 4, 6 and 8 weeks of outdoor exposure, the packets were opened and each board was visually examined for extent of fungal discoloration over its upturned surface. The degree of discoloration was assessed to nearest 5%, as a percentage of the area of fungal discoloration over the area of the entire surface, using a scale from 0 (no discoloration) to 100% (complete discoloration).

3. RESULTS and DISCUSSION

Among nine moldicides tested, two moldicides (designated as moldicide A and mlodicide B) were appeared to be compatible with CCA (Table 1). Moldicide A is a domestic moldicide

Table 2. Weather information in field exposure site during the outdoor exposure*1

Exposure period	Temperature (°C)			Mean relative humidity (%)	Total rainfall (mm)
	Min.	Max.	Mean		
First 2 weeks (07/16/05 ~ 07/29/05)	22.95	27.18	25.13	83.67	489.0
Second 2 weeks (07/30/05 ~ 08/12/05)	24.27	27.59	25.61	84.50	1,142.0
Third 2 weeks (08/13/05 ~ 08/26/05)	16.96	26.72	23.13	79.02	384.0
Fourth 2 weeks (08/27/05 ~ 09/09/05)	20.58	23.95	22.63	76.99	34.0

*1 Whether information was obtained from monthly weather reports provided by Korea Meteorological Service.

Table 3. Ability of selected chemicals to inhibit mold of CCA-treated radiata pine in small-scale laboratory evaluations*1

Moldicide	Concentration	Degree of discoloration (%)		
		4 weeks	6 weeks	8 weeks
	(% total a.i.*4)	(rating)		
Control I*2		32.6 (6.2)	40.4 (6.5)	41.3 (7.0)
Control II*3		29.5 (8.0)	38.1 (6.9)	46.9 (8.0)
A	0.00025	23.3 (4.6)	36.2 (7.1)	38.1 (7.2)
	0.0005	20.8 (3.3)	31.7 (6.1)	34.3 (5.8)
	0.001	16.5 (4.2)	21.3 (6.8)	26.0 (6.7)
	0.002	9.6 (3.6)	8.7 (4.0)	9.6 (3.7)
	0.004	2.7 (2.5)	3.1 (2.9)	6.5 (2.3)
B	0.00037	32.1 (6.4)	36.9 (4.8)	43.9 (7.0)
	0.00075	23.2 (6.4)	28.0 (6.3)	36.7 (5.8)
	0.0015	14.2 (6.2)	23.7 (5.3)	30.2 (8.6)
	0.003	0.0 (0.0)	2.0 (2.7)	13.7 (8.6)
	0.0045	0.0 (0.0)	1.4 (2.3)	5.0 (6.0)

*1 Each value represents the mean of 14 samples and values in parentheses represent one standard deviation.
*2 Radiata pine treated with distilled water.
*3 Radiata pine treated with 2% CCA solution.
*4 Active ingredient.

which is produced as a fungicide for general purpose, and moldicide B is an imported moldicide which is currently used in domestic CCA treatment plants.

3.1. Laboratory Trials

Table 3 gives laboratory test data for two moldicides treated at a range of concentrations. Like untreated samples, samples treated with 2% CCA without the addition of moldicide appeared to be highly susceptible to surface mold, suggesting that chemical protection may pose a greater challenge with CCA treated wood. This greater mold susceptibility reflects that CCA is not effective for controlling surface mold.

Table 4. Ability of selected chemicals to inhibit mold of CCA-treated radiata pine in field trials*1

Moldicide	Concentration	Degree of discoloration (%)		
		4 weeks	6 weeks	8 weeks
	(% total a.i.*3)	(rating)		
Control*2		22.8 (15.2)	26.9 (19.2)	30.0 (19.0)
A	0.0005	14.1 (8.4)	14.4 (8.5)	28.1 (17.0)
	0.001	5.7 (3.3)	8.9 (6.6)	12.9 (8.0)
	0.002	7.1 (3.2)	8.9 (5.6)	11.4 (8.4)
	0.003	6.4 (5.0)	6.8 (4.6)	10.0 (10.4)
	0.004	2.9 (3.2)	3.9 (3.5)	4.6 (3.1)
B	0.00075	13.9 (9.8)	23.6 (13.4)	24.6 (12.6)
	0.0015	12.9 (8.0)	17.1 (16.7)	21.4 (23.5)
	0.003	7.1 (4.7)	8.2 (5.8)	9.6 (6.9)
	0.0045	2.1 (2.6)	3.2 (3.7)	5.4 (3.1)
	0.006	0.4 (1.3)	1.8 (3.2)	1.8 (3.0)

*1 Each value represents the mean of 16 samples and values in parentheses represent one standard deviation.
*2 Radiata pine treated with 2% CCA solution.
*3 Active ingredient.

As has been frequently used in the past in several literatures (Miller and Morrell 1989, Miller *et al.* 1989, Miller and Morrell 1990, Morrell *et al.* 1998, Kim *et al.* 1999), the arbitrary figure of 15% mean degree of discoloration has been used to determine the protection threshold. With this level of discoloration, surface mold is barely visible to the naked eye. Thus, any treatment for which less than a 15% mean degree of discoloration was recorded was deemed successful in protecting CCA mold. On the basis of this criterion, both moldicides provided effective control of mold fungi for at least one concentration for 8 weeks.

During the whole test periods (8 weeks), moldicides A and B produced acceptable protection to surface mold at the concentration of 0.002% or higher and at the concentration of 0.003% or higher, respectively. These data should provide the basis for field trials to confirm performance of moldicides under more commercial conditions.

3.2. Field Trials

The efficacy of moldicides incorporated with 2% CCA solution in field trials is summarized in Table 4, and any treatments with discoloration degrees of 15% of less were deemed effective as mentioned in laboratory trials. Surface mold developed on boards treated with 2% CCA solution without the addition of moldicide after 2 weeks of storage. Thus, exposure conditions were ideal for mold growth and discoloration, indicating the severity of the field exposure.

Moldicide A provides markedly superior protection with lower concentration compared to moldicide B. Moldicide A provided acceptable protection against mold fungi at all concentrations evaluated through the 6 weeks of exposure. After 8 weeks, moldicide A was effective at the concentration of 0.001% or higher. In boards treated with moldicide B, all concentrations were effective after 4 weeks and treatment with 0.003% or higher could keep a good performance after 6 weeks of exposure. As a result, the optimal concentrations of moldicide A and B incorporated with 2% CCA solution were determined as 0.001% and 0.003%, respectively. Since exposure conditions of treated boards in these tests were much more severe than normal practice, better performance of moldicides tested could be expected under more realistic field conditions.

In general, results of the laboratory trials were similar to those in the field trials (Miller and Morrell 1989). However, the better performance of moldicide A in the field tests in comparison with in the laboratory tests was not surprising because environmental conditions for fungal discoloration was different between both tests, suggesting that the effectiveness of moldicides must be evaluated through the field tests.

4. CONCLUSIONS

From nine commercial modicides tested, moldicide A, a formulation containing 2-n-octyl-4-isothiazoline-3-one and moldicide B, a formulation containing 5-chloro-2-methyl-4-isothiazolin-3-one and 2-methyl-4-isothiazolin-3-one were selected as CCA compatible moldicides. The results of field trials indicate that moldicide A can provide markedly superior protection with lower concentration compared to moldicide B. The optimum concentration of moldicides A and B incorporated with 2% CCA solution was determined as 0.001% and 0.003% for long-term protection (8 weeks), respectively.

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