Wood Preservation Technology Applicable to Waferboard And Oriented Strandboard

By

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EXECUTIVE SUMMARY

The Literature Review presented here was undertaken as part of a study on "Improving the Market Potential of Waferboard and Oriented Strand Board by Preservative Treatments". The review indicated the following main findings:

(i) Untreated waferboard/OSB are susceptible to bio-deterioration by fungal organisms under conditions favouring decay (i.e. when moisture, temperature and oxygen are optimal).

(ii) Several chemical preservatives are effective to protect waferboard/OSB against fungal and insect deterioration. Preservatives may be added during primary manufacture, either prior to or during blending. Fabricated boards can be sprayed, brushed, dipped or pressure-treated with a preservative.

(iii) Post-fabrication treatments via spraying, brushing or dipping provide good surface protection for use in low to moderate environmental hazards. Oil-based preservatives e.g. copper napthenate, bis-tributyl-tinoxide offer more effective surface uptake and retention than water-based chemicals. This is due to the densified, waxy and somewhat "water repellant" surface of waferboard/OSB.

Water-borne treatment also causes irreversible edge swelling of the panels. Pressure treatment is undesirable because it causes considerable thickness swelling often accompanied by significant loss in strength.

(iv) The simplest and most effective way to add appropriate preservatives is during blending. Powdered preservatives can be mixed with powdered resins, dissolved in liquid resins, or added separately to the wood furnish either before or after resin application. Azaconazole, copper-sulphur micronized salt (FNG) and copper carbonate may be applied this way because they have low water solubility and are stable at common pressing temperatures. It appears that powdered phenol-formaldehyde (PF) resins are more compatible with preservatives than are liquid PF resins. Isocyanate resins show a broader range of compatibility with preservatives than PF resins.

(v) Effective water-borne preservatives (such as copper and zinc salts, boron formulations, copper-chromium compounds) can best be incorporated into waferboard/OSB by mixing chemicals into wax emulsions, and adding them to wafers during the blending operation.

Ammoniacal copper and zinc salts, copper-chromium compounds and the proprietary formulations Difolatan and Wolmanit-C10, were found to be effective at relatively low retention levels. Strength retentions are generally better when preservatives are added to the wax.

(vi) The issues of environmental concerns, long term performance, compatibility with fasteners, market acceptance, and codes/standards need to be addressed in future R & D.

(vii) Waferboard/OSB are entering a new phase of market diversification in their development. While the panels have become strongly established in the traditional sheathing applications of construction, they are being up-graded and used for siding, composite beams, containers, just to name a few. Concrete form-work, preserved wood foundations, and industrial construction are also strong possibilities. All these applications require not only excellent mechanical properties of the panels but also good dimensional stability, improved durability and improved fire rating. Thus, the use of chemical preservatives and fire retardants are becoming important issues in the manufacture and use of waferboard both in domestic and international markets.

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Incorporation of Chemical Preservatives into Wood Composites

Chemical preservatives can be incorporated into wood composite panels in a variety of ways. Preservatives can be added to the wood particles, wax or resin. Fabricated boards can be sprayed, brushed, dipped or pressure-treated with a preservative. Particles can be treated (e.g. swelling agents) so as to increase preservative retention, or to reduce decay susceptibility (e.g. acetylation) to reduce preservative retention required. These methods all have limitations - some altering board properties and others having limited effectiveness. The different ways of incorporating preservatives into wood composites and their limitations will be discussed in this section.

1.1: Spraying, Dipping, and Brushing of Panels

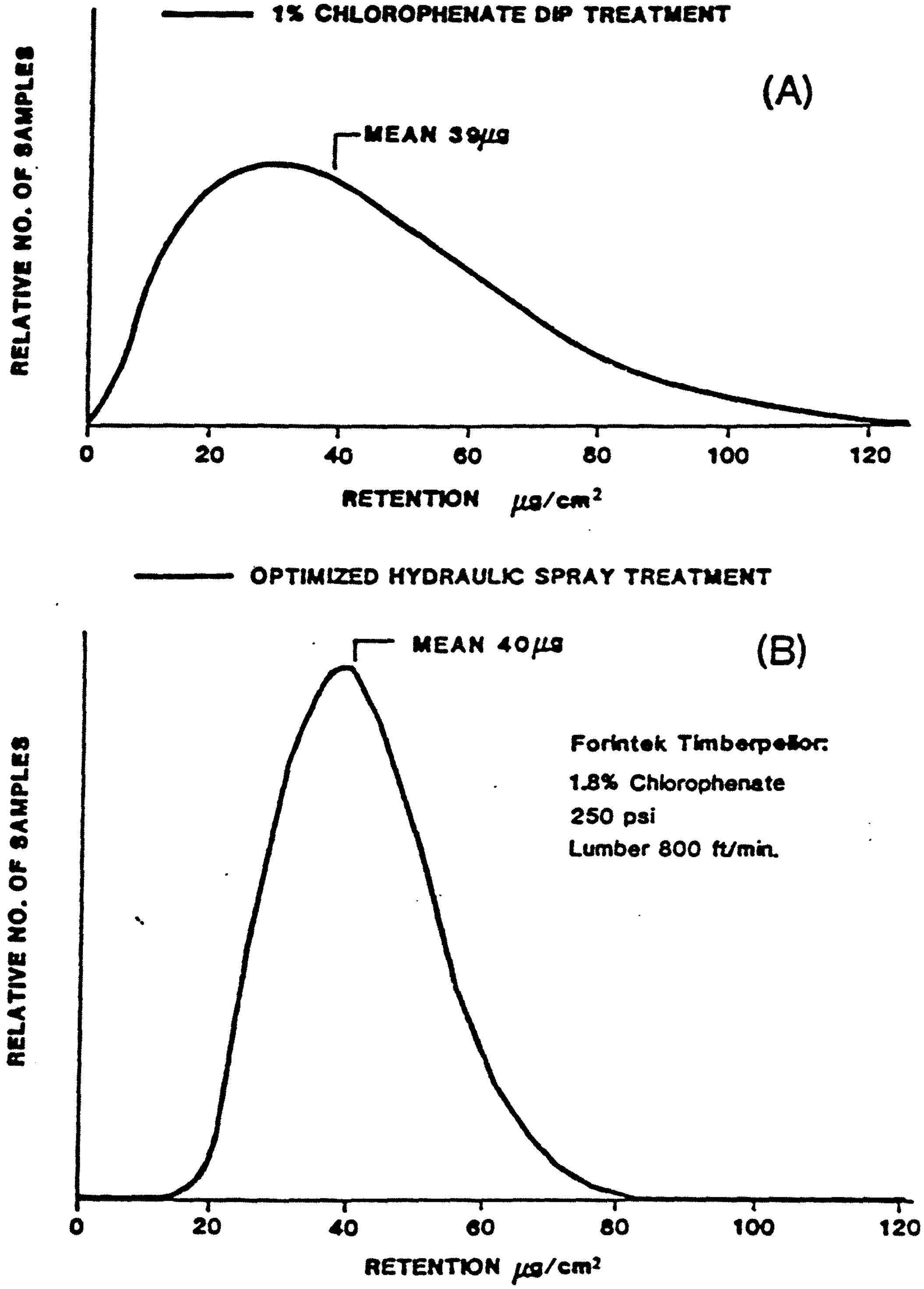
Perhaps the simplest way to apply a chemical to a wood composite panel involves spraying, dipping or brushing of the preservative. As a rule, changes in strength properties will be minimal. However, the extent of penetration and hence effectiveness is limited. These methods do however provide both the consumer and the producer with effective methods of improving biodeterioration resistance.

One hazard associated with dip tanks, especially drive-in dip tanks, is the large quantity of chemical contained which could spill. Automated dip tanks contain less chemical but some of their parts can corrode in some preservative solutions. Spraying uses less mixed preservative than either of the dipping tanks. It does however require filters and return systems to recycle overspray (3). Uniform coverage with spray treatments also presents a problem.

Even though spray treatments require chemical recovery systems and uniform coverage can be more difficult, their popularity is increasing. In 1982, in British Columbia, 45 dip tanks (12 of the drive-in type) and 60 spray systems were in use. Three years later, 88 spray systems were in use compared to only 36 dip tanks (6 of the drive-in type) (3). Part of the increase in spray system may be attributable to less mixed chemical being required and stricter environmental protection laws. Retentions of chemical appear to be more uniform in sprayed boards, which could also contribute to their rising popularity. This is shown in Figure 1.1 (3). It was suggested that during dipping, rough spots absorb more of the chemical thus causing the skewed higher retentions.

Figure 1.2 (6) shows preservative incorporation with respect to time for veneer sheet and plywoods dipped in water-based and oil-based preservatives. It shows that after one or two minutes, most preservative that will be picked up on the surface has been absorbed. This amount varies with preservative type (water-based, oil-based) and perhaps wood species (fir, beech), density (of the wood species and between veneer sheets and plywood) or manufacturing stresses (densification and/or subsequent fissuring of wood's microstructure, lathe checks from peeling). Depending on the method of determining preservative incorporation, wood thickness may also be an influencing factor.

Figure 1.1: Frequency Distribution of Chemical Retention Obtained (A) in Dip Treatment of Hem-Fir and SPF Lumber and (B) in Spray Treatment Using Hydraulic Spray System



For non-pressure preservative treatment methods (dipping, brushing, spraying), the degree to which treatment can be achieved with organic-based solvents varies with the permeability of the wood surface, treating solution properties and contact time (13). As visible in Figure 1.2, preservative uptake during immersion occurs rapidly in the beginning but becomes slower with time. The initial quick uptake results from rapid absorption by the exposed surface and slower penetration (and absorption) occurs through capillary pathways. When removed from treating solution contact, the preservative continues to penetrate into the wood while the solvent evaporates from the surface (13). Similar to Figure 1.2, Figure 1.3a (13) shows preservative absorption of water-borne and oil-borne chemicals. Both show higher absorptions of the water-based formulations. Figure 1.3b (13) gives penetration for the same chemicals used in Figure 1.3a. Since water-borne chemicals have higher absorption, it would be expected that their penetration would be deeper but this does not occur. The higher viscosity of creosote as compared to the organic solvent explains the reduced penetration of the former. The water-based chemical has an even lower viscosity so penetration should be deeper still. Again this does not happen. The authors suggest that since non-polar solutions (organic-based) do not interact with wood, their penetration is solely determined by surface tension and viscosity of the solution. For water-borne solutions penetration is also determined by the wood-water contact angle and the

Figure 1.2: Incorporation of Preservative in Relation to the Dipping Time of Veneer Sheets and 5L-plywood Using Water- and Oil- borne Preservatives

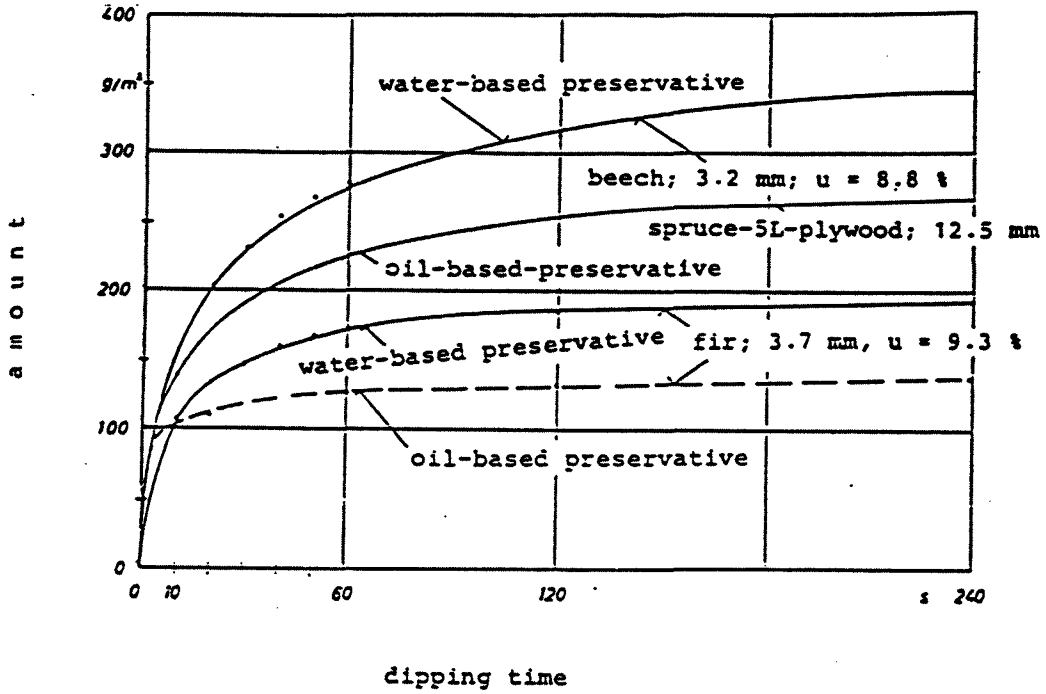


Figure 1.3a: Effect of Type of Preservative on Absorption in Pine Sapwood Treated by Immersion

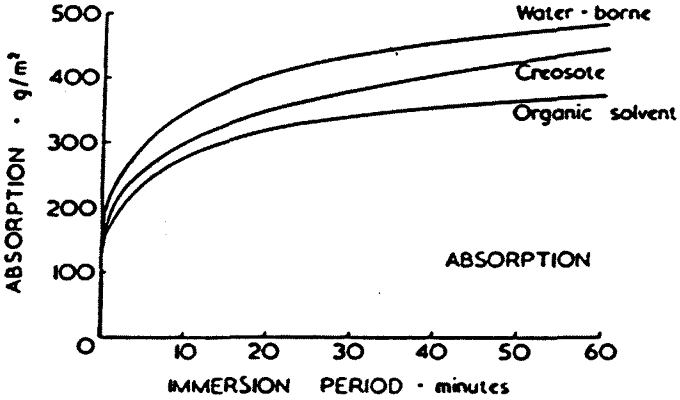
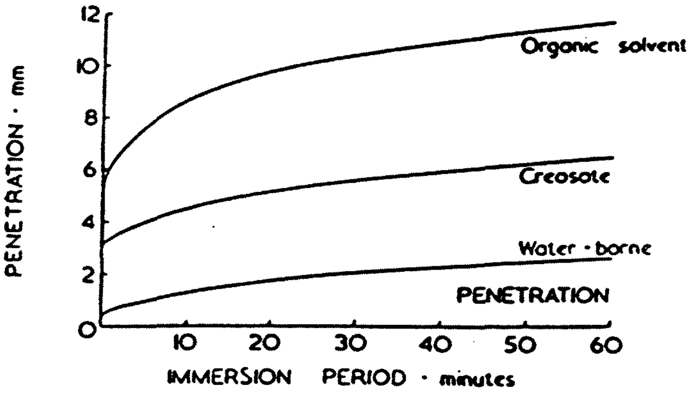


Figure 1.3b: Effect of Type of Preservative on Penetration in Pine Sapwood Treated by Immersion



swelling properties of water.

This has direct implications to the dipping of wood composites. Water-borne preservative solutions will most likely have minimal penetration into the panel products even after extended lengths of immersion (60 minutes). Further, densification of the material as well as the presence of sizing agents may reduce penetrability. If long dipping times are used, in addition to the expenses involved (having large amounts of chemical and equipment on hand to treat rapidly produced panels), strength changes will occur as pressing stresses are released and thickness swelling occurs. Internal bond strength will be reduced and boards will require planing to smooth rough surfaces. It therefore appears that organic-based solvents should be used if preservative treating is through panel immersion. Surface roughening via sanding or light incising would also help to increase surface absorption. Slowed fixation of the preservative might aid in increasing penetration.

White lauan plywood was dipped for thirty minutes in different concentrations of water-borne (chromium-fluorine mixture (CF-2), copper chrome arsenate (CCA) and copper chrome borate (CCB)) and solvent borne (copper naphthenate (Cu-Nap), pentachlorophenol (PCP) and bis(tributyltin)oxide (TBTO)) (12). Brush treatments on plywood, applied to obtain maximum absorption, were also compared. Half of the samples were weathered and all were tested for decay resistance according to standards (JIS-A-9302-1966) for three months. Tyromyces palustris and Coriolus versicolor were inoculated on water-borne treated samples while C. versicolor and Polystictus sanguineus were inoculated on the solvent-borne treated samples. Solvent-borne brush treatments were not conducted. Retentions are shown in Table 1.1 for all preservatives and weight losses are shown in Table 1.2 along with the average and standard deviation weight loss for all exposure types. For the water-borne treatments, the best preservative appears to be CF-2 at 5%. Dipping performed slightly better than brushing. Note that brushing involved two applications of preservative and in all likelihood, only a single brushing would occur commercially. Results would therefore be expected to be poorer for brush treatments. Dipping for thirty minutes is probably much too long for commercial fabrication so again weight losses can be expected to be higher. For solvent preservative types, all three performed well with copper naphthenate the best. Doubling the concentration of TBTO did not have much of an improvement on decay resistance. For weight losses caused by C. versicolor, samples dip-treated with copper naphthenate were lowest followed by the other solvent-borne treatments and then the water-borne treatments.

Sapwood blocks were end sealed with epoxy resin and then brush treated with different preservatives (20). Some blocks were weathered and all were exposed to monocultures of Coriolus versicolor, Tyromyces palustris, and Serpula lacrymans for eight weeks according to JWPA Standard-(1) 1979. Preservatives used and their ranking are given in Table 1.3. Three rankings were

Table 1.1: Preservative Retentions for White Lauan Plywood

Preservatives	Concen. (%)	Retention			
		Dipping		Brushing	
		kg/m^3	g/m^3	kg/m^3	g/m^3
<u>Water</u>-<u>borne</u>					
CF-2	5	3.10	6.85	2.00	4.41
	2	1.22	2.69	0.71	1.56
CCA	5	2.61	5.76	1.74	3.84
	2	1.12	2.48	0.74	1.62
CCB	5	2.46	5.43	1.53	3.37
	2	1.00	2.20	0.65	1.43
<u>Solvent</u>-<u>borne</u>					
PCP	3	2.59	5.72	----	----
TBTO	1	0.82	1.83	----	----
	0.5	0.44	0.98	----	----
Cu-naphthenate	3(Cu)	2.29^*	5.04^*	----	----
* = retention as	copper				

performed on the means of the six different exposures (3 wood species by 2 weatherings). From the ranking for best concentration from each category, it can be seen that tributyltin phthalate (at 1%) performed the best in mycotoxic effectiveness (calculated as nine times the difference in weight loss of control and treated blocks expressed as a percentage of untreated block weight loss). This was followed by zinc naphthenate (at 5%) and then Busan 30 (at 2%). These three chemicals (and concentrations) keep their respective rank when mycotoxic effectiveness (or value of efficiency) is required to be above 90%. If however effectiveness is required to be above 85% within one standard deviation from the mean, number three

Table 1.2: Changes in Weight Loss of Plywood Treated with Preservatives After a Three Month Decay Test (DIP/BRUSH)					
Preservatives	Concen. (%)	Weight Loss (%)			
		T. Palustris		*C. versicolor*	
		NOT W	W*	NOT W	W
DIPPING					
Water-borne					
UNTREATED		19.4	18.7	19.0	17.5
CF-2	5	0.0	1.4	0.0	10.9
	2	0.0	5.0	5.0	15.6
CCA	5	2.3	4.8	7.2	14.8
	2	2.6	4.9	16.9	17.4
CCB	5	2.9	4.6	7.6	15.9
	2	5.4	5.5	14.5	20.5
Solvent-borne					
UNTREATED		19.0	17.5	12.5	10.6
PCP	3	3.7	5.9	2.0	0.1
TBTO	1	2.0	5.4	1.2	0.7
	0.5	0.9	6.3	3.5	1.2
Cu-naphthenate	3(Cu)	1.5	0.2	1.7	0.5
BRUSHING					
UNTREATED		19.4	18.7	19.0	17.5
Water-borne CF-2	5	0.0	3.7	0.1	14.2
	2	3.3	4.5	9.5	18.4
CCA	5	5.3	3.1	18.5	16.9
	2	1.3	5.3	18.9	14.9
CCB	5	2.2	3.9	15.5	19.0
	2	14.1	30.1	19.0	17.5

NOT W = NOT WEATHERED; W = WEATHERED

Table 1.3: Mycotoxic Effectiveness for Weathered and Nonweathered Sapwood Blocks Exposed to Different Decay Fungi

Preservative/ Concen. (%)		Mean* and (Std. Dev.)	Mean - 1 Std. Dev.	RANKING		
				I	II	III
A	0.50	79.2 (30.34)	48.86			
	0.75	81.8 (29.07)	52.73			
	1.00	94.3 (8.78)	85.52	6	7	12
	0.50	87.2 (18.16)	69.04			
B	0.75	94.3 (10.82)	83.32		7	
	1.00	98.5 (2.81)	95.69	1	1	1
	2.00	65.2 (33.20)	32.00			
C	4.00	79.7 (17.24)	62.46			
	6.00	95.3 (6.19)	89.11	4	4	6
	1.00	34.0 (16.50)	17.50			
D	3.00	75.0 (20.05)	54.95			
	5.00	75.3 (16.34)	58.96			
	1.00	87.0 (14.42)	72.58	12		
E	3.00	92.3 (5.16)	87.14	10	13	9
	5.00	89.5 (3.21)	86.29			11
	1.00	33.7 (28.20)	5.50			
F	3.00	63.5 (31.20)	32.30			
	5.00	63.2 (25.13)	38.07			
	1.00	72.3 (20.53)	51.77	13		
G	3.00	93.8 (5.31)	88.49		9	7
	5.00	96.5 (4.09)	92.41	2	2	2
	1.00	58.2 (13.98)	44.22			
H	3.00	91.2 (7.44)	83.76		16	
	5.00	91.7 (3.50)	88.20	11	15	8
	1.00	63.2 (24.86)	38.34			
I	3.00	92.3 (8.21)	84.09		13	
	5.00	95.2 (3.54)	91.66	5	5	3
	0.50	70.2 (38.99)	31.21			
J	1.00	72.5 (38.88)	33.62			
	2.00	83.2 (20.29)	62.91			
	3.00	93.7 (8.69)	85.01	7	10	13
	1.00	84.7 (21.44)	63.26			

Table 1.3: Mycotoxic Effectiveness continued

Preservative/ Concen. (%)		Mean* and (Std. Dev.)	Mean - 1 Std. Dev.	RANKING		
				I	II	III
K	1.50	95.0 (8.15)	86.85		6	10
	2.00	96.3 (5.82)	90.48	3	3	4
	0.50	48.0 (32.14)	15.86			
L	0.75	60.0 (26.60)	33.40			
	1.00	89.2 (6.31)	82.89			
	1.25	93.5 (4.32)	89.18	8	11	5
	0.50	84.2 (22.12)	62.08			
M	0.75	83.7 (22.38)	61.32			
	1.00	91.0 (10.58)	80.42		17	
	1.25	93.5 (10.07)	83.43	8	11	

*Average of nonweathered and weathered samples of three wood species (_F_. _crenata_, _C_. _japonica_, and _P_. _densiflora_) exposed to three fungi (_C_. _versicolor_, _T_. _palustris_, and _S_. _lacrymans_) respectively.

I Highest mean per preservative ranked
II Preservative concentrations above 90% ranked
III Preservative concentrations above 85% (after subtraction of one std. deviation) ranked.

Mycotoxic Effectiveness: calculated as nine times the difference in weight loss of control and treated blocks expressed as a percentage of untreated block weight loss

A = Tributyltin oxide
B = Tributyltin phthalate
C = Tribromophenol
D = Pentachlorophenyl laurate
E = Copper naphthenate
F = Copper-8-quinolinolate
G = Zinc naphthenate
H = Zinc neodecanoate
I = Zinc versatate
J = Aluminum salt of N-nitroso-N-cyclohexylhydroxyl-amine
K = 2-(thiocyanomethylthio)benzothiazole
L = 3-ethoxycarbonyloxyl-1-bromo-1,2-iod-1-propene
M = 4-chlorophenyl-3-iodo-propagylformal

becomes zinc versatate (at 5.0%).

1.2: Adding Preservatives to Panels' Primary Constituents

1.2a: Introduction

Preservatives can be added to wood particles (varying in size from veneer sheets to particles) or to resins and waxes. For plywood, preservatives can be added to the glueline or to the veneer sheets (immersion, spraying, brushing or forced impregnation). For particleboard and waferboard, the preservative could be added to the wood (dipping, spraying) to the wax, or to the resin. It can be added in as a powder or as a liquid in the blenders or in the resins and sizing agents. Adding a preservative in any of these ways must result in strength losses (at a given resin level).

1.2b: Preservative Treatments for Plywood

Pretreating plywood veneers with preservatives can cause several problems (5). Gluing may be more difficult. Impregnation treatments of veneers will require drying prior to assemblage and which can cause additional cracking and warping. Full panel treatment may produce boards with poor inner lamina treating (from poor permeability of gluelines) and also due to the size of the sheets being treated.

Adding a preservative to the glueline eliminates some of these problems. Additional drying is not required thus eliminating additional cracking and warping. Interior treatment will be more uniform. This is one of the simplest methods of treating plywood (and other composites) since it does not require any additional operation or alteration to machinery layout (21).

However, gluing problems can result and surfaces are poorly treated. Any preservative added in this manner must be miscible with adhesives used and must not cause excessive strength reductions (5). It must also be resistant to leaching and volatilization and compatible to pressing temperatures. The preservative must also be able to protect wood at considerable distances from the glueline (5). This can occur in four ways (5): (1) movement into cracks and fissures during spreading, (2) flow caused by cold prepressing and early pressing, (3) volatilization during hot pressing, and (4) movement from the glueline by vapourization while in service.

Work with sodium pentachlorophenate-plywood glueline treatment has not been successful since severe strength loss occurred (5, 10) which was attributed to surface contamination (10). Other tests have shown that this chemical as well as sodium 4, 6-dinitro-o-cresolate (Na-DNOC), the potassium salt of N-nitroso-N-cyclohexyl-hydroxylamine (NCH-K), sodium fluoride, and bis (n-tributyltin) oxide protected white luaun plywood against a brown rot fungus, Tyromyces palustris, when added to the glueline (21). None of these preservatives were effective against Coriolus versicolor, a white rotter, in similar tests. IF-1000 (4-chlorophenyl-3-iodopropargyl formal) and EBIP (3-ethoxycarbonyloxy-1-bromo-1,2-diiodopropene) have shown promising results for plywood glueline treatments although success may vary with veneer thickness, wood species, composition of veneers, and amount of chemical added (21). Veneer pretreatment may therefore be a better method.

1.2c Preservative Treatments for Particleboard

Wood composites can have preservatives incorporated into their structure via pressure treating of the panel, by adding the chemical to resins or waxes, or by pretreating the particles (1). Pressure treating requires additional drying and also causes considerable stress release (requiring surface smoothing in addition to normal edge trimming). Strength can be considerably reduced and chemical costs may be high. The need for so much chemical being used, as in pressure treating, must be considered carefully to ensure cost competitiveness with treated plywood or consumer-targeted brush-on preservatives.

Adding a preservative to wood composites' components is not without problems. Strength can be considerably reduced. As an example, phenol-formaldehyde-bonded flakeboards made from ammonical copper arsenite treated flakes had lower moduli of rupture and internal bond values than untreated panels (both before and after aging) (8). These strength reductions may be due to pH alteration, resin-preservative incompatibility, changes in resin viscosity, decreases in wood wetability, fewer bonding sites and mechanical interference of bonding sites (1).

1.2c.i Particle Pretreatment

Aspen flakes (at approximately 100% moisture content) were immersed in CCA or ACA to two retention levels (0.2 and 0.4 pcf). Boards of similar densities were produced from resole or novolac phenol-formaldehyde resin after the preservatives were allowed to slowly diffuse into flakes for several days. One percent wax and 2.5% resin were used for all boards (1). Table 1.4 (1) shows strength reductions for all board types as compared to controls. It also gives strength reduction due to accelerated aging and, comparisons can be made to control accelerated age results.

1.4: Properties of Preservative-treated Waferboard Types-(FLAKES)

treating chemicals (pcf)	panel dens. (pcf)	STRENGTH REDUCTIONS DUE TO PRESERVATIVE						% ** dif. thick. swell
		MOR n-a	MOR* (%)	MOE (%)	MOE* (%)	IB (%)	IB* (%)	
RESOLE RESIN								
0.0	41.4		26.2[1]		12.3[1]		69.3[1]	
0.2 ACA	41.6	18.5[1]	49.0	2.5[1]	24.0	39.8[1]	86.8	-18.2
0.4 ACA	40.5	6.6	37.1	-15.9	21.3	31.8	66.7	28.0
0.2 CCA	41.7	26.5	51.4	0.1	31.7	33.0	88.1	-22.4
0.4 CCA	40.6	25.9	50.4	-4.9	40.0	47.7	87.0	-39.9
NOVOLAC RESIN								
0.0	40.9		33.1		7.3		82.6	
0.2 ACA	41.0	3.3	42.2	-4.9	21.4	13.0	65.0	52.0
0.4 ACA	40.6	-6.9	38.7	-7.4	21.8	17.4	52.6	51.3
0.2 CCA	41.4	1.7	41.8	-0.6	19.2	36.2	65.9	31.4
0.4 CCA	41.4	10.6	36.6	-0.9	23.8	50.7	73.5	36.8

* reduction by aging
** as calculated by (control - treated/control) * 100
n-a non-aged samples used
[1] (control-treated)/control x 100%

Several trends are apparent in Table 1.4.

1) Inclusion of either ACA or CCA in waferboard panels made from a novolac resin generally results in lower MOR, MOE and IB strength reductions than panels made from resole phenol formaldehyde resins (as compared to % difference from controls).

2) Strength reductions may be more severe for boards made from CCA-treated flakes than ACA-treated flakes.

3) Aging might have less of an impact on strength reduction for boards make from ACA-treated flakes than CCA-treated flakes.

4) Greater improvements in dimensional stability (reduced thickness swell) occurs in ACA-treated followed by CCA-treated flakes of novolac type phenol formaldehyde-bonded boards.

5) Retention level increases may cause an increased reduction in MOR and IB of CCA and ACA-treated novolac boards; however, this trend is not observable for either MOR or IB of resole-bonded boards.

Thus it appears that ACA-treated flakes bonded with a novolac type of phenol formaldehyde resin will produce the best board type when strength reduction is the sole criterion. However, reduction in strength is not the only criterion. Mean strengths and variances, as well as improvements in decay resistance, appearance and treating difficulties must also be considered. Tables 1.5 (1) and 1.6 (8) give strength values for waferboard made form ACA- and CCA-treated flakes.

Table 1.5: Strength Properties of Unaged Waferboard Made From Pretreated Flakes

Resin Type	(pcf) Treating Chemicals	(pcf) Density	(psi) MOR	(1000 psi) MOE	(psi) IB	(%) Irr T.S.
Resole	0.0	41.4	3780	710	88	14.3
	0.2 ACA	41.6	3080	692	53	16.9
	0.4 ACA	40.5	3530	823	60	10.3
	0.2 CCA	41.7	2780	709	59	17.5
	0.4 CCA	40.6	2800	745	46	20.0
Novolac	0.0	40.9	3600	669	69	27.7
	0.2 ACA	41.0	3480	733	60	13.3
	0.4 ACA	40.6	3850	751	57	13.5
	0.2 CCA	41.4	3540	703	44	19.0
	0.4 CCA	41.4	3220	705	34	17.5

From Table 1.5, novolac-phenol-formaldehyde-bonded boards are seen to be weaker in MOR, MOE, and IB than similar boards bonded with a resole-type phenol-formaldehyde resin. Upon addition of ACA or CCA via pretreatment of flakes, novolac-bonded boards are stronger in MOR than resole-bonded boards at similar retention levels. Internal bond and MOE generally remain somewhat weaker. Retention level of ACA (with the exception of 0.0 pcf) does not appear to influence board breaking strength as visible in Table 1.6. This table also shows that an increase in resin content can improve MOR, MOE and IB properties. Increasing resin content can however be very expensive, and as seen from Table 1.6, strength improvements increase at a much slower rate than resin content (roughly a 21% increase in MOR from 5 to 8% resin). Flake thickness can be increased to improve internal bond strength but with increased thickness swell resulting (7). Since thickness swell is reduced through pretreatment of flakes with ACA, any increase in dimensional

Table 1.6: Strength Properties of Unaged Phenol-formaldehyde*-bonded Flakeboard Made From ACA Pretreated Ghanaian Hardwood Flakes

(%) Resin	(pcf) Preservative Level	(pcf) Density	(psi) MOR	(1000 psi) MOE	(psi) IB
5	0.0	47.3	4780	709.6	178
5	0.2	46.1	3850	614.3	152
5	0.4	46.0	3910	614.8	149
5	0.6	46.9	4010	647.6	137
8	0.0	50.0	5800	791.4	240
8	0.2	48.4	4650	735.1	205
8	0.4	48.9	4920	773.2	209
8	0.6	48.8	4980	781.6	210

* liquid phenol-formaldehyde resin (CASCOPHEN PB65)

instability caused by thicker flakes shouldn't be serious. Using thicker flakes will however reduce chemical penetration to the flake centre thus requiring slightly longer treating times, longer diffusion periods, or use of more poorly treated flakes. With increased flake thickness, susceptibility to decay may also increase as it does for plywood ply thickness (6).

Soil block tests using *Gloeophyllum trabeum* and *Coriolus versicolor* were performed (14) on boards used in Table 1.6. ACA-treated panels were very resistant to the white-rotter *C. versicolor* but less so to the brown rotter *G. trabeum*. Weight and IB losses for these boards are given in Table 1.7 (14).

Table 1.7: Percent Weight Loss and Internal Bond Loss of Waferboard Made From ACA-treated Ghanian Hardwood Flakes

	(pcf)	(pcf)	Weight loss %				Internal Bond (psi)		
(%)	ACA	Panel	*G. t.*		*C. v.*		before	after	
resin		dens.	Act.	Imp.	Act.	Imp.		*G.t.*	*C.v.*
5	0.0	47.3	7.2		30.8		176	85	23
5	0.2	46.1	3.6	50.0	2.4	92.2	155	68	70
5	0.4	46.0	2.6	63.9	2.3	92.5	139	67	46
5	0.6	46.9	2.3	68.1	2.6	91.6	143	70	62
8	0.0	50.0	3.4		8.8		245	187	128
8	0.2	48.4	3.8	-11.8	3.2	63.6	198	123	130
8	0.4	48.9	3.2	5.9	3.3	62.5	181	128	141
8	0.6	48.8	3.0	11.8	2.8	68.2	179	128	138

Act. = actual weight loss (%)
Imp. = percent improvement over control
G.t. = *Gloeophyllum trabeum*
C.v. = *Coriolus versicolor*

From Table 1.7, the following trends are apparent:

1) Increasing resin content resulted in improved decay resistance for both fungal species.

2) For nonweathered samples exposed to G. trabeum with a resin content of 8%, the addition at any of the three concentrations used does not appear to improve decay resistance.

3) For nonweathered samples constructed using 8% resin and exposed to either fungus, the addition of a preservative does not have as dramatic an improvement in decay resistance as at 5% resin content.

4) Doubling or tripling the ACA preservative level does not cause a similar improvement in decay resistance for samples exposed to C. versicolor or G. trabeum.

These trends change however, when panels are subjected to accelerated aging. Increasing resin content still improves decay resistance of samples exposed to both fungal species. Unlike the nonweathered samples, the addition of ACA to panels made with 8% resin content provides improved decay resistance to both fungal species. This may be due to swelling (which takes place in accelerated aging) making the boards more susceptible to decay, loss of excess formaldehyde which inhibits fungal growth, or a combination of these factors and others. Doubling or tripling the ACA preservative level does cause a similar improvement in decay resistance against G. trabeum. This is not the case for samples exposed to C. versicolor.

In the absence of accelerated aging, it appears that the best treatment to use, one which provides adequate decay resistance coupled with minimum strength loss and minimum chemical cost, is a board constructed with 5% resin and an ACA treating level between 0.2 and 0.4 pcf. This minimized resin and chemical preservative used with only light strength reductions as compared to higher treating concentrations. Decay resistance is only marginally improved beyond this concentration range. With aging, higher resin contents should be used to limit strength losses and treating solution concentrations should be low.

1.2c.ii: Adding a Preservative to Resin

Powdered preservatives can be mixed with powdered resins, dissolved in liquid resins, or added separately to the wood furnish either before or after resin application. Azaconazole (Rodewod) in the form of a micronized buff-coloured powder, has been found to be effective against decay fungi at concentrations as low as 0.25% active ingredient (17). Azaconazole (1-[[2-(2,4-dichlorophenyl)-1,3-dioxolan-2-yl]methyl]-14H4-,2,4-triazole), as well as FNG, a copper and sulfur micronized formulation, have low water solubility and stability at common pressing temperatures (16, 17). These two preservatives were added to phenol-formaldehyde-bonded and polymeric-isocyanate-bonded aspen waferboard and randomly aligned strand board respectively (16, 17). Tumbling flakes were sprayed with wax then powdered resole phenol-formaldehyde resin followed by one of the powdered preservatives. Strands were blended with Rubinate MF-184 polymeric diphenylmethane diisocyanate, a PMDI resin, followed by wax and then one of the powdered preservatives. Azaconazole was also dissolved in the PMDI resin and the resulting mixture was sprayed on the strands. Samples (leached and nonleached) were exposed to two brown rot fungi, *Gloeophyllum trabeum* and *Poria placenta*, and one white rot fungus, *Coriolus versicolor*, for eight weeks in agar-block tests. Weight losses for leached and nonleached samples as well as strength properties for nondecayed samples are given in Table 1.8 (16, 17).

Table 1.8: Strength Properties and Weight Losses of Preservative-treated Particleboards - (RESIN)

	PF-bonded			PMDI-bonded		
	Density (g/cm^3)	MOE (MPa)	IB (kPa)	Density (g/cm^3)	MOE (MPa)	IB (kPa)
Control	0.694	5910	611	0.658	4520	363
Aza. (powder)	0.692	5720	630	0.642	4320	363
FNG (powder)	0.679	5410	597	0.609	3970	310
Aza. (resin)				0.622	4040	310

	Weight Loss (%) PF-bonded		Weight Loss (%) PMDI-bonded	
	Non-leached	Leached	Non-leached	Leached
Controls				
<u>G</u>. <u>trabeum</u>	13.0	18.0	16.7	20.4
<u>C</u>. <u>versicolor</u>	12.5	15.8	24.5	14.9
<u>P</u>. <u>placenta</u>		13.6	----	9.4
Azaconazole				
<u>G</u>. <u>trabeum</u>	4.2	8.2	4.7	5.5
			15.7 (res.)	10.7 (res.)
<u>C</u>. <u>versicolor</u>	0.1	0.0	0.4	0.0
			0.6 (res.)	0.5 (res.)
<u>P</u>. <u>placenta</u>		1.6	---	0.7
				0.0 (res.)
FNG				
<u>G</u>. <u>trabeum</u>	16.9	15.3	18.0	19.7
<u>C</u>. <u>versicolor</u>	12.5	9.5	5.9	5.2
<u>P</u>. <u>placenta</u>		13.1	----	10.5

Observations that can be made from Table 1.8 include the following:

1. FNG, when added as a powder, reduced IB strength unlike the powder application of Azaconazole.

2. Azaconazole, when dissolved in resin, reduced IB strength.

3. PF-bonded control boards were much stronger (IB, MOR) than their PMDI-bonded counterparts. This may however be due to density differences or particle shape differences.

4. Azaconazole (as a powder) performed better (lower weight losses) in decay tests than FNG.

5. When dissolved in resin, Azaconazole performed poorly in decay tests. The authors attribute this poor performance to reduced preservative distribution or to a reduced amount of preservative available to restrict decay, especially decay caused by <u>Gloeophyllum</u> <u>trabeum</u>.

Aspen waferboard made with liquid resole phenol-formaldehyde resin were made with and without the addition of preservative to the resin prior to fabrication (18). Either an aqueous copper and fluorine mixture or tributyltin oxide and mono-chloronaphthalene were mixed into the liquid resin and resulting furnishes were pressed at 210°C and 3.5 MPa for 7.5 or 8.5 minutes. Control panels were fabricated using powdered resin at similar concentrations as the liquid resins (3% powdered resin solids).

Field tests were conducted in Mississippi and Minnesota for 30 months. Panels were edge sealed and either installed on a fence post or buried to half their depths. Results are given in Table 1.9.

It appears that the addition of either the TBTO-chloronaphthalene mixture or the copper-fluorine mixture do not improve strength durability of aspen waferboard. It would be expected that the addition of a preservative to waferboard, although reducing strength initially as compared to untreated controls, should limit strength loss due to decay and thus provide superior performance after exposure as compared to untreated controls. This however, was not the case and suggests that preservative treating via incorporation into resin is not an adequate method to improve panel durability. Thickness swell was highest for these two preservatives suggesting that the incorporation of a preservative into resin interferes with resin bonding. This could account for poor strength retentions following 30 months of exposure.

Table 1.9: Waferboard Strength Properties Following 30 Months of Exposure I - (RESIN)

	Load at Failure (kg)*	MOE (MPa)*	MOR (MPa)	Control MOR (MPa)
<u>Test Fence</u>				
Untreated	939	3900	18.4	29.7
Copper and Fluorine	930	3550	16.1	28.5
TBTO and Chloronaphthalene	807	3490	17.8	26.8
<u>Above Groundline</u>				
Untreated	830A	4120A	19.5A	
Copper and Fluorine	717A	3630A	17.0A	
TBTO and Chloronaphthalene	748A	3940A	19.4A	
<u>Below Groundline</u>				
Untreated	239	1020A	3.9A	
Copper and Fluorine	334A	2020A	7.5A	
TBTO and Chloronaphthalene	405A	1980A	8.2A	

* - combined site average
Values followed by the same letter are not significantly different (Protected LSD, alpha=0.05 for Load at failure and MOR; alpha=0.5 for MOE).

Four preservatives were mixed into liquid or powdered phenolic resin and added to aspen flakes (at 3% resin solids) (9). Pressing at 210°C and 3.4 MPa for 7.5 minutes formed furnishes blended with liquid resin into waferboard. Pressing

Table 1.10: Physical and Mechanical Properties of Preservative-Treated Aspen Waferboard I - (RESIN)

Panel Type	Density (g/cm^3)	MOR (MPa)	% Reduction in MOR	MOE (MPa)	% Reduction in MOE
A	0.678	29.7	----	5437	----
B	0.681	33.2	-11.8	5823	-7.1
C	0.692	31.7	----	5366	----
D_1	0.684	30.4	4.1	5449	-1.5
D_2	0.692	30.0	5.4	5142	4.2
E_1	0.692	27.4	13.6	5250	2.2
E_2	0.704	26.8	15.5	5330	0.7
F_1	0.707	29.9	5.7	5725	-6.7
F_2	0.686	28.5	10.1	5264	1.9

Panel Type	IB (kPa)	% Reduction in IB	AA MOR loss (%)	AA MOE loss (%)	AA ITS (%)
A	538	----	18	9.8	23.2
B	558	-3.7	29	21.6	7.4
C	455	----	24	5.4	27.8
D_1	483	-6.2	14	6.4	28.2
D_2	462	-1.5	24	2.9	31.2
E_1	448	1.5	11	0.2	31.4
E_2	496	-9.0	16	5.6	29.7
F_1	427	6.2	44	15.8	36.5
F_2	352	22.6	43	10.0	36.2

A	control - powdered resin
B	cis-N-[1,1,2,2-tetrachloroethyl thia]-4-cyclohexene-1,2-dicarboximide 0.25% (Difolatan) -----> a.s.r.
C	control - liquid resin
D_1	2-(thiocyanomethylthio) benzothiazole (Busan 30) 0.11% active solids retention
D_2	2-(thiocyanomethylthio) benzothiazole (Busan 30) 0.15% active solids retention
E_1	chloronaphthalene and tributyltinoxide * 1.0% stock solution
E_2	chloronaphthalene and tributyltinoxide * 1.4% stock solution
F_1	aqueous copper and fluorine mixture ** 0.70% active solids retention
F_2	aqueous copper and fluorine mixture ** 0.98% active solids retention
*	Basileum SP 70
**	Wolmanit C10

time was increased to 8.5 minutes and pressure increased to 3.6 MPa for furnishes blended with powdered resin. Physical and mechanical properties of these boards are given in Table 1.10 along with chemical names and treating concentrations of the preservative used.

Control panels made with liquid resin were stronger in MOR but weaker in IB and MOE than similar panels made with powdered resin. Panels made with liquid resin had higher irreversible thickness swell than panels made with powdered resin. The addition of Difolatan (B) to powdered resin caused an increase in MOR, MOE, and IB strength. Adding preservatives to liquid resin, resulted in decreased MOR strength and generally decreases in MOE and IB strength as well.

These panels were subjected to three different decay tests (19): soil-block, three month contact block, and suspension in sealed glass jars for six weeks after dipping in a spore suspension. Results for these different tests are given in Table 1.11. The three month contact block test was designed to simulate above ground uses. Emphasis should therefore be placed on its results since it most closely models typical decay hazards.

From Table 1.11, the preservatives showing promise for improving board decay resistance are Basileum SP 70 (E_1, E_2) and Wolmanit C10 (F_1, F_2) (when considering contact block test results). Soil-block test results for these two preservatives are somewhat poorer for accelerated aged specimens but still show an improvement over untreated controls. Strength reductions (MOR) following accelerated aging are high for Wolmanit C10 treated boards as is irreversible thickness swelling and reduction in internal bond strength (Table 1.10). Basileum SP 70

Table 1.11: Decay Test Results for Preservative-treated Aspen Waferboard I - (RESIN)

Panel Type	Spore Suspension Dip/ Six Weeks in Glass Jar					
	(1)	(2)	(3)	(4)	(5)	(6)
A	5*	5*	5*	5*	5*	5*
B	5	5	5	5	5	5
C	3	4.6	4.6	5	5	3.4
D_1	2.4	4	4.6	5	5	3
D_2	3	5	3	5	3	2.4
E_1	1.2	2.8	4.2	4.5	3.4	2.8
E_2	1	1	3.6	4.2	2	2.5
F_1	3.2	5	4	5	5	4.4
F_2	3.5	3.5	4	4.5	4	4

Panel Type	3 Month Contact Block Test **				Soil block test **			
	(7)	(8)	(9)	(10)	(7)	(8)	(9)	(10)
A	27	28	23	21	32	39	42	37
B	23	25	17	24	25	27	34	37
C	25	29	8	10	23	40	21	29
D_1	26	30	6	10	29	45	24	35
D_2	25	27	10	10	26	44	22	34
E_1	5	13	0	4	9	39	5	22
E_2	3	14	2	4	5	27	3	17
F_1	3	6	2	3	13	30	1	2
F_2	1	4	1	3	10	18	8	9

* appearance rating
0 = no growth
2 = 6 - 20%
4 = 51 - 80%

** percent weight loss
1 = trace to 5%
3 = 21 - 50%
5 = 81 - 100%

(1) - *Penicillium* sp. control
(2) - *Penicillium* sp. aged
(3) - *Cladosporium* sp. control
(4) - *Cladosporium* sp. aged
(5) - *Aureobasidium* sp. control
(6) - *Pullulano* sp. aged
(7) - *G. trabeum* control
(8) - *G. trabeum* aged
(9) - *P. placenta* control
(10) - *P. placenta* aged

treated boards show slightly less irreversible thickness swell and internal bond strength loss than Wolmanit C10 treated panels; however, their reduction in MOR strength is greater. Surface moulding was slightly less for boards treated with Basileum SP 70 than Wolmanit C10.

Mixing resin and preservative together prior to blending does not appear to provide adequate protection to waferboard from decay and can cause considerable strength loss. However, results from some research suggests that strength loss may be minimal and improved durability adequate. Questions relating to durability must still be answered, though. It must be determined whether enough preservative is present to inhibit preservative degrading organisms and if chemical toxicity is altered by the extreme conditions endured during pressing alter chemical toxicity. Suitability to current mill operations and processes must be investigated. Durability tests must be performed with other fungi to prove or disprove the suitability of this method of incorporation. Finally, other methods of incorporation must be carefully considered so that preservative and resin costs as well as plant alteration costs can be minimized, and bonding strength and durability maximized.

1.2c.iii: Adding a Preservative to Wax

Table 1.12 gives strength properties of aspen waferboard bonded with phenol-formaldehyde resin following 30 months of exposure in Minnesota and Mississippi (as in Table 1.9) (18). These boards were preservative-treated with an aqueous copper and fluorine mixture or ammonical copper arsenate which had been mixed with a wax emulsion prior to blending. Strength properties were assessed at three locations: below groundline, above groundline and on test fence specimens. It can be seen from the data that ACA added to the wax emulsion considerably reduced the severity of exposure in soil block tests. Above groundline strengths are similar for the two preservative-treated panels and for the untreated panel with the exception of load at failure in which the latter panel was found to be significantly weaker than the former panels. It appears from these results

Table 1.12: Waferboard Strength Properties
Following 30 Months of Exposure II - (WAX)

	Load at Failure (kg)*	MOE (MPa)*	MOR (MPa)*	Control MOR (MPa)
<u>Test Fence</u>				
Untreated	939	3900	18.4	29.7
Copper and Fluorine	884	3640	18.2	37.4
ACA	1030	3490	19.7	28.5
<u>Above Groundline</u>				
Untreated	830	4120A	19.5A	
Copper and Fluorine	984A	4140A	20.4A	
ACA	975A	4160A	19.6A	
<u>Below Groundline</u>				
Untreated	239A	1020A	3.9A	
Copper and Fluorine	314A	1710A	6.8A	
ACA	748	3940	18.7	

* - combined site average
Values followed by the same letter are not significantly different (Protected LSD, alpha=0.05 for Load at failure and MOR; alpha=0.5 for MOE).

that adding a preservative to the wax emulsion may provide adequate protection with minimal strength loss.

Similar to the boards generating Tables 1.10 and 1.11, preservatives were mixed with wax and incorporated into waferboard panels to determine any strength reductions and decay resistance these chemicals caused (9). For these boards however, the preservatives were mixed with wax prior to blending (instead of resin). Results of these tests are given in Tables 1.13 (9) and 1.14 (19).

Table 1.13 Physical and Mechanical Properties of Preservative-treated Aspen Waferboard II - (WAX)

Panel Type	Density (g/cm^3)	MOR (MPa)	% Reduct. in MOR	MOE (MPa)	% Reduct. in MOE
A	0.678	29.7	----	5437	----
B	0.704	37.4	-25.9	6226	-14.5
C	0.713	29.4	1.0	5876	-8.1
D	0.696	28.5	4.0	5564	-2.3

Panel Type	IB (kPa)	% Reduct. in IB	AA MOR loss (%)	AA MOE loss (%)	AA ITS (%)
A	538	----	18	9.8	23.2
B	545	-1.3	26	19.4	6.0
C	427	20.6	59	22.5	44.8
D	448	16.7	15	13.9	8.0

A	control - powdered resin at 3% resin solids
B	aqueous copper and fluorine mixture 0.98% active solids
C	chromated copper arsenate 0.98% active solids retention
D	ammonical copper arsenate 0.61% active solids retention

Addition of CCA, ACA or Wolmanit C10 caused an increase in board stiffness and only a slight decrease in MOR strength as compared to controls. Internal bond strength was considerably reduced with the exception of boards treated with Wolmanit C10.

Irreversible thickness swelling was very poor (almost double from control boards) for CCA-treated samples.

Table 1.14: Decay Test Results for Preservative-treated Aspen Waferboard II - (WAX)

Panel Type	Spore Suspension Dip/ Six Weeks in Glass Jar					
	(1)	(2)	(3)	(4)	(5)	(6)
A	5*	5*	5*	5*	5*	0*
B	4.6	3.6	4.6	5	3.8	1.5
C	4	5	5	5	0.2	0
D	2.2	3.8	5	5	0	0

Panel Type	3 Month Contact Block Test **				Soil block test **			
	(7)	(8)	(9)	(10)	(7)	(8)	(9)	(10)
A	27	28	23	21	32	39	42	37
B	5	6	1	3	24	29	3	11
C	1	3	1	2	5	11	1	3
D	1	2	1	2	2	3	0	1

* appearance rating
0 = no growth
2 = 6 - 20%
4 = 51 - 80%

** percent weight loss
1 = trace to 5%
3 = 21 - 50%
5 = 81 - 100%

(1) - Penicillium sp. control
(2) - Penicillium sp. aged
(3) - Cladosporium sp. control
(4) - Cladosporium sp. aged
(5) - Aureobasidium sp. control
(6) - Pullulano sp. aged
(7) - G. trabeum control
(8) - G. trabeum aged
(9) - P. placenta control
(10) - P. placenta aged

A control - powdered resin at 3% resin solids
B aqueous copper and fluorine mixture 0.98% active solids
C chromated copper arsenate 0.98% active solids retention
D ammonical copper arsenate 0.61% active solids retention

Compared to control panels, preservative treated panels performed well both in three month contact tests and soil block tests. Results with spore suspension dip and six weeks exposure in glass jar tests were poor for preservative-treated panels, but better than control panels.

Incorporation of a preservative into a wood composite panel by blending chemicals into wax emulsions appears to provide good decay resistance and at the same time not really reducing strength except perhaps internal bond strength. Difficulties with wax-preservative compatibility must be examined. Spray techniques must be improved upon to avoid blotchy treating. Reduced internal bond strength should be more fully studied in an attempt to minimize strength loss. Powdered preservative should be studied more thoroughly to determine if they can be mixed successfully with wax and provide an alternative to liquid preservatives.

1.2d: Comparing Different Methods of Preservative Incorporation

Several methods of preservative treating waferboard and oriented strandboard have been discussed. These methods include dipping or spraying the completed panel or pressure impregnating finished panels and incorporation of preservatives into wood particles, resin, wax or at a separate blending stage. Each of these methods has advantages and disadvantages associated with them. Some considerably alter a composite panel's mechanical properties while others provide limited durability to decay.

Probably the easiest methods of increasing board durability are those which are applied to the panel itself. Dip treating, spraying and pressure treating provide manufacturers with an on/off switch for preservative treating. Produced panels can easily be treated or not treated simply by adjustments at the end of the production line. These methods also allow other secondary industries to further increase product value instead of the manufacturer. In addition, dipping, brushing, and spraying provide consumers with the opportunity to increase panel durability through store bought formulations without the extra expense of having the manufacturer carry out the process. It also enables the consumer to use different levels of treating (through number of applications or intensity) for different severities of exposure.

Dipping, spraying and brushing cause minimal strength reductions; however, extended dipping times could conceivably cause much thickness swelling and consequently decreased internal bond strength. Pressure treating will cause much strength loss, thickness swelling and perhaps flake delamination. Thickness swelling will make resurfacing necessary. Abnormal chemical absorption may result during dipping. This might cause extreme variation in surface appearance if a colouring preservative is used. Each of these methods has limited penetration to panel interiors and each will require some amount of time for drying. Limited penetration can be partially corrected by increasing dipping time or to a lesser extent by increasing the intensity of brushing/spraying, but with increased thickness swell resulting. Using organic-based preservatives will increase penetration and hence reduce chemical contact time so thickness swelling should be less severe. Sizing agents however might impede penetration. The role that sizing agents play should therefore be investigated.

Dipping and pressure treating require large quantities of chemicals to be contained. With this containment come risks of spillage and human injury. Quantities of chemical required for spray treatments are less; however, these operations are more complex because they require filter and recovery systems. These systems have an advantage over direct incorporation of a preservative into board furnish: Chemicals are not subjected to extreme heat and pressure which could reduce preservative efficacy.

Adding preservatives to board furnish (to the particles, wax or resin) is more complex than treating a whole panel. Distribution of preservatives is however much more uniform and additional drying is not required for these methods, unlike dipping, brushing, spraying, and pressure treating. Reduced internal bond strength will most likely be reduced unless additional resin is added. Gluing may be more difficult if the preservative is not compatible with resins used or if the chemical blocks bonding sites. Without using high preservative retentions, it might be possible that insufficient resin is present (due to good distribution) to prevent biodeterioration caused by more resistant organisms. It is also possible that volatilization of a preservative will occur during pressing or that high pressing temperatures will somehow reduce chemical efficacy.

Experiments comparing strength reductions and improved durability caused by different treatments have been conducted, some of which will be discussed in the remainder of this subsection. Eight preservatives were incorporated into aspen waferboard in wax, in resin, as a flake pretreatment, by dipping or by pressure treating (18, 19). Strength properties are shown in Table 1.15. Table 1.16 ranks MOR, MOE and IB as a percent of control strength and also ranks irreversible thickness swell. Durability properties are given in Table 1.17 and their ranking for performance in Table 1.18.

Some treatments made boards stronger than controls and others weaker (Table 1.15). Similarly, some treatments improved durability while others reduced it (Table 1 .16). From Table 1.17, several observations can be made.

1. Boards performing well in one strength category did not necessarily do the same in other strength categories.

2. Board durability rankings varied with the different tests.

3. Thickness swell performance does not appear to be correlated with any of the three strength properties.

4. The top five performing treatments for minimum strength reduction are (in decreasing order): C, B, L_1, D, and E.

5. The top five performing treatments for minimum irreversible thickness swell are (in descending order): I, H, C, B, and E.

6. The top five performing treatments for maximizing durability are (in descending order): J, E, I, H, and D.

7. The five treatments showing overall best performance are (in descending order): E, C, J, and, B and I.

It therefore appears that powdered resins are more compatible with preservatives than are liquid resins. It also seems as if adding a preservative to the wax emulsion (E, C, D), in conjunction with powdered resins, provide optimum protection and strength retention. This is however based on the assumption of equal weighting of decay, strength and irreversible thickness swelling and also that differences in board density do not influence strength or durability. The latter assumption cannot be dismissed lightly since strength and density, and to some extent durability and density, are positively correlated. This experiment should therefore be assessed for density interaction and possibly repeated using better target density calculations. Other fungi and different durations of exposure time should also be studied.

Consider Table 1.18 (18), which gives strength properties for preservative-treated aspen waferboard exposed for 30 months in Minnesota and Mississippi. This table includes Table 1.9, in which the preservative was mixed with resin, and Table 1.12, in which preservatives were added to wax. In addition, Table 1.18 includes samples that had been dip-treated and then exposed. Initial modulus of rupture values vary from 25.8 to 37.4 MPa. Although this variation is somewhat large, some observations can be made.

1. Although the strongest board type initially was that treated with copper and fluorine in the wax, following exposure dip treatment in copper-8-quinolinolate, followed by treatment with ammonical copper arsenate added to wax for panels on test fences were strongest.

2. Above groundline concluding strength retentions were similar with the exception of load at failure for CF-wax treatment and ACA-wax treatments which were found to be significantly stronger. These are unexpected results considering original starting strengths.

3. Below groundline tests gave no significant differences between treatments for any of the strength categories. The only exception being boards made from wax mixed with ACA which were found to be significantly stronger than the other boards in each of the categories.

This work also confirms that the addition of ammonical copper arsenate to wood composites (specifically waferboard) via incorporation into a wax emulsion provides, in some cases, superior performance to other preservatives and to different methods of preservative incorporation. Atomization should therefore be carefully considered so that an even distribution of the wax preservative mixture can be ensured. Efforts should also be made to understand why a preservative can be incorporated into wax successfully without major strength reduction and still provide durability, and why preservative incorporation into resin appears to be inadequate in these two areas. Considering the concern over arsenic toxicity, ammonical copper compounds should also be investigated for suitability in application and durability.

1.3: Heat Accelerated Fixation

Work (15) with copper-chromate-arsenate treated pine and hardwood stakes showed that rate of fixation, as controlled by temperature, influenced performance in the latter type of stake. Preserved hardwood stakes in which heat accelerated fixation had occurred performed poorly when compared with similar stakes in

Table 1.15: Physical and Mechanical Properties of Preservative Treated Aspen Waferboard III - (DIP/PRESSURE/WAX/RESIN/FLAKES)

Panel Type	Density (g/cm^3)	MOR (MPa)	% Reduction in MOR	MOE (MPa)	% Reduction in MOE
A	0.678	29.7	-----	5437	-----
B	0.681	33.2	-11.8	5823	-11.8
C	0.704	37.4	-25.9	6226	-25.9
D	0.713	29.4	1.0	5876	-8.1
E	0.696	28.5	4.0	5564	-2.3
F	0.696	29.6	0.3	5350	1.6
G	0.678	25.8	13.1	4896	10.0
H	0.630	22.5	24.2	4047	25.6
I	0.607	21.7	26.9	3937	27.6
J	0.678	26.9	9.4	5528	-1.7
K	0.692	31.7	-----	5366	-----
L_1	0.684	30.4	4.1	5449	-1.5
L_2	0.692	30.0	5.4	5142	4.2
M_1	0.692	27.4	13.6	5250	2.2
M_2	0.704	26.8	15.5	5330	0.7
N_1	0.707	29.9	5.7	5725	-6.7
N_2	0.686	28.5	10.1	5264	1.9
O	0.691	20.4	31.3	5344	1.7

Panel Type	IB (KPa)	% Reduction in IB	AA MOR loss %	AA MOE loss %	AA ITS (%)
A	538	-----	18	9.8	23.2
B	558	-3.7	29	21.6	7.4
C	545	-1.3	26	19.4	6.0
D	427	20.6	59	22.5	44.8
E	448	16.7	15	13.9	8.0
F	448	16.7	26	8.3	24.0
G	469	12.8	7	-0.5	13.4
H	365	32.2	19	8.7	0.7
I	303	43.7	27	11.6	0.6
J	345	35.9	39	25.5	11.8
K	455	-----	24	5.4	27.8
L_1	483	-6.2	14	6.4	28.2
L_2	462	-1.5	24	2.9	31.2
M_1	448	1.5	11	0.2	31.4
M_2	496	-9.0	16	5.6	29.7
N_1	427	6.2	44	15.8	36.5
N_2	352	22.6	43	10.0	36.2
O	310	42.4	75	64.9	38.7

A - powdered PF control
B - Difolatan 0.25% active solids retention - mixed in powdered resin
C - Wolmanit C10 0.98% a.s.r. - in wax, powdered resin
D - CCA 0.98% a.s.r. in wax, powdered resin
E - ACA 0.61% a.s.r. in wax, powdered resin
F - Cu-8-quinolinolate 0.03% solids retention dip powdered resin
G - 3-iodo-2-propynyl butyl carbamate 0.03% solids retention dip powdered resin
H - CCA - 0.62 pcf a.s.r. - pressure treated powdered resin (4%)
I - ACA - 0.57 pcf a.s.r. - pressure treated powdered resin (4%)
J - ACA 0.98% active solids pretreated flakes powdered resin
K - liquid PF - control
L_1 - Busan 30 0.11%
L_2 - 0.15% a.s.r. in liquid resin
M_1 - Basileum SP 70 1.0%
M_2 - 1.4% stock solution mixed in liquid resin
N_1 - Wolmanit C10 0.70%
N_2 - 0.98% a.s.r. in liquid resin
O - formaldehyde and sulfur dioxide 1% Net wt. gain -flake pretreatment - powdered resin

which fixation had occurred at ambient temperatures. The authors suggested that heat-accelerated fixation might alter chemical relationships within the preservative components themselves as well as between the preservative and the wood so that even though the preservative might still be located within the wood structure, performance would be reduced.

At ambient conditions, CCA fixation occurs through cation exchange of copper ions and intermediate fixation of chromium complexes. These reactions give final fixation products of ion exchanged copper, chromium and copper arsenates and chromic hydroxide (15). Under heat-accelerated fixation, these products would most likely be different. This does not explain however,

Table 1.16: Decay Test Results for Preservative-Treated Aspen Waferboard III - (DIP/PRESSURE/RESIN/WAX/FLAKES)

Panel Type	Spore Suspension Dip/ Six Weeks in Glass Jar					
	(1)	(2)	(3)	(4)	(5)	(6)
A	5*	5*	5*	5*	5*	5*
B	5	5	5	5	0	0
C	2.6	3.6	4.6	5	3.8	1.5
D	4	5	5	5	0.2	0
E	2.2	3.8	5	5	0	0
F	2	3.5	4.4	5	2	1.4
G	0.6	5	5	5	0	0.4
H	0.2	1	5	5	4.6	0.8
I	0	2.2	3	4.5	0	0
J	1	1.6	5	5	0	0
K	3	4.6	4.6	5	5	3.4
L_1	2.4	4	4.6	5	5	3
L_2	3	5	3	5	3	2.4
M_1	1.2	2.8	4.2	4.5	3.4	2.8
M_2	1	1	3.6	4.2	2	2.5
N_1	3.2	5	4	5	5	4.4
N_2	3.5	3.5	4	4.5	4	4
O	5	5	5	5	0	0

Panel Type	3 Month Contact Block Test **				Soil block test **			
	(7)	(8)	(9)	(10)	(7)	(8)	(9)	(10)
A	27	28	23	21	32	39	42	37
B	23	25	17	24	25	27	34	37
C	5	6	1	3	24	29	3	11
D	1	3	1	2	5	11	1	3
E	1	2	1	2	2	3	0	1
F	15	22	18	25	14	31	33	43
G	16	23	17	22	34	38	33	39
H	2	2	1	1	4	4	2	3
I	4	3	3	4	2	2	3	2
J	0	1	0	1	0	1	0	1
K	25	29	8	10	23	40	21	29
L_1	26	30	6	10	29	45	24	35
L_2	25	27	10	10	26	44	22	34
M_1	5	13	0	4	9	39	5	22
M_2	3	14	2	4	5	27	3	17
N_1	3	6	2	3	13	30	1	2
N_2	1	4	1	3	10	18	8	9
O	22	20	24	29	25	33	32	42

A - powdered PF control
B - Difolatan 0.25% active solids retention - mixed in powdered resin
C - Wolmanit C10 0.98% a.s.r. - in wax, powdered resin
D - CCA 0.98% a.s.r. in wax, powdered resin
E - ACA 0.61% a.s.r. in wax, powdered resin
F - Cu-8-quinolinolate 0.03% solids retention dip powdered resin
G - 3-iodo-2-propynyl butyl carbamate 0.03% solids retention dip powdered resin
H - CCA - 0.62 pcf a.s.r. - pressure treated powdered resin (4%)
I - ACA - 0.57 pcf a.s.r. - pressure treated powdered resin (4%)
J - ACA 0.98% active solids pretreated flakes powdered resin
K - liquid PF - control
L_1 - Busan 30 0.11%
L_2 - 0.15% a.s.r. in liquid resin
M_1 - Basileum SP 70 1.0%
M_2 - 1.4% stock solution mixed in liquid resin
N_1 - Wolmanit C10 0.70%
N_2 - 0.98% a.s.r. in liquid resin
O - formaldehyde and sulfur dioxide 1% Net wt. gain -flake pretreatment - powdered resin

* appearance rating
0 = no growth
2 = 6 - 20%
4 = 51 - 80%

** percent weight loss
1 = trace to 5%
3 = 21 - 50%
5 = 81 - 100%

(1) - *Penicillium* sp. control
(2) - *Penicillium* sp. aged
(3) - *Cladosporium* sp. control
(4) - *Cladosporium* sp. aged
(5) - *Aureobasidium* sp. control
(6) - *Pullulano* sp. aged
(7) - *G. trabeum* control
(8) - *G. trabeum* aged
(9) - *P. placenta* control
(10) - *P. placenta* aged

the differences in performance between hardwoods and softwoods. If initially there is a difference in susceptibility to decay for the two wood types, then perhaps alteration to fixation products could further make one of the wood types, in this case the hardwood stakes, additionally susceptible. The authors suggest that copper may form less available complexes that are toxic to

Table 1.17: Ranking for Strength of Preservative-treated Aspen Waferboard (unaged)-(DIP/PRESSURE/RESIN/WAX/FLAKES)

Type	MOR	MOE	IB	Total	Rank	ITS
A	--	--	--	--	--	--
B	2	3	3	8	2	4
C	1	1	5	7	1	3
D	4	2	11	17	4	16
E	5	5	9	19	5	5
F	3	9	9	21	7	8
G	11	14	8	33	12	7
H	14	15	13	42	15	2
I	15	16	16	47	16	1
J	9	6	14	29	10	6
K	--	--	--	--	--	--
L_1	6	7	2	15	3	9
L_2	7	13	4	24	9	11
M_1	12	12	6	30	11	12
M_2	13	8	1	22	8	10
N_1	8	4	7	19	5	14
N_2	10	11	12	33	12	13
O	16	10	15	41	14	15

Panel Type	Spore	Contact	Block	Total	Rank	Total	Total Rank**
A	--	--	--	--	--	--	--
B	10	15	12	37	14	20	4
C	13	8	10	31	10	14	2
D	9	4	5	18	5	25	8
E	4	2	2	8	2	12	1
F	7	14	11	32	11	26	9
G	4	13	16	33	12	31	12
H	6	2	4	12	4	21	6
I	1	6	3	10	3	20	4
J	3	1	1	4	1	17	3
K	--	--	--	--	--	--	--
L_1	15	11	15	41	16	28	10
L_2	12	11	13	36	13	33	15
M_1	8	9	9	26	8	31	12
M_2	2	10	8	20	6	24	7
N_1	16	6	7	29	9	28	10
N_2	14	5	6	25	7	32	14
O	10	16	14	40	15	44	16

* - assumes equal importance of strength reductions (MOE, MOR, IB); and, assumes equal importance of decay (spore suspension, contact block, soil block)

** - assumes that the overall rankings for decay and strength reductions are of equal importance to each other, and to that for irreversible thickness swell.

A - powdered PF control
B - Difolatan 0.25% active solids retention - mixed in powdered resin
C - Wolmanit C10 0.98% a.s.r. - in wax, powdered resin
D - CCA 0.98% a.s.r. in wax, powdered resin
E - ACA 0.61% a.s.r. in wax, powdered resin
F - Cu-8-quinolinolate 0.03% solids retention dip powdered resin
G - 3-iodo-2-propynyl butyl carbamate 0.03% solids retention dip powdered resin
H - CCA - 0.62 pcf a.s.r. - pressure treated powdered resin (4%)
I - ACA - 0.57 pcf a.s.r. - pressure treated powdered resin (4%)
J - ACA 0.98% active solids pretreated flakes powdered resin
K - liquid PF - control
L_1 - Busan 30 0.11%
L_2 - 0.15% a.s.r. in liquid resin
M_1 - Basileum SP 70 1.0%
M_2 - 1.4% stock solution mixed in liquid resin
N_1 - Wolmanit C10 0.70%
N_2 - 0.98% a.s.r. in liquid resin
O - formaldehyde and sulfur dioxide 1% Net Wt. gain -flake pretreatment - powdered resin

fungi or also that under accelerated fixation less diffusion of the toxicant into susceptible cell wall areas occurs. In their opinion, heat-accelerated fixation of hardwoods for use in ground contact is unwise.

Table 1.18: Waferboard Strength Properties Following 30 Months of Exposure III - (RESIN/WAX/DIP)

		Method of Incorporation	Load at* Failure (kg)	MOE* (MPa)	MOR* (MPa)	Control MOR (MPa)
Test Fence						
UNT	p[1]	None	939	3900	18.4	29.7
CF	l	Resin	930	3550	16.1	28.5
TBTO	l	Resin	807	3490	17.8	26.8
CF	p	Wax	884	3640	18.2	37.4
ACA	p	Wax	1030	3490	19.7	28.5
IPBC		Dip	880	3940	18.9	25.8
CU8	p	Dip	975	3750	20.5	29.6
Above Groundline						
UNT	p	None	830 B[2]	4120 A	19.5 A	
CF	l	Resin	717 B	3630 A	17.0 A	
TBTO	l	Resin	748 B	3940 A	19.4 A	
CF	p	Wax	984 A	4140 A	20.4 A	
ACA	p	Wax	975 A	4160 A	19.6 A	
Below Groundline						
UNT	p	None	239	1020 A	3.9 A	
CF	l	Resin	334	2020 A	7.5 A	
TBTO	l	Resin	405	1980 A	8.2 A	
CF	p	Wax	314	1710 A	6.8 A	
ACA	p	Wax	748 A	3940 B	18.7 B	

UNT - untreated
CF - copper and fluorine mixture 0.98% active solids retention
TBTO - tributyltin oxide and chloronaphthalene - 1.4% by weight stock solution
IPBC - 3-iodo-2-propynyl butyl carbamate 0.03% solids retention
CU8 - copper-8-quinolinolate - 0.03% solids retention
ACA - ammonical copper arsenate - 0.61% active solids - 4 kg/m^3 equivalent retention
1 powdered resin used - p, liquid resin used - l
* combined site average
2 values followed by the same letter are not significantly different (Protected LSD, alpha = 0.05 for load at failure and MOR; alpha = 0.5 for MOE)

Using pencil-size stakes of *P. patula* that had been impregnated with CCA, the effect of heat-accelerated fixation on decay, termite resistance and element leachability was studied

(4). Different retentions were tested and samples were subjected to different combinations of air and heat drying. It was found that:

> 1. "... At a specific temperature, whether CCA-treated timber is subjected to heat treatment directly after impregnation, or after allowing most of the fixation reaction to occur before subjecting it to heat treatment, the permanence of the preservative is equally affected at a specific temperature."
>
> 2. "... The percentages of elemental Cu, Cr and As are converted to leachable compounds and/or leach, in different relative proportions according to the initial preservative retention."

At low retentions there is a shift to CCA-A, and at high retentions there is a shift to CCA-B when starting with CCA-C.

> 3. "... total elements leached becomes more marked for temperatures in the order of 80°C to 100°C and higher (i.e. an increase of more than four times from air dry to 120°C). This effect appears to be independent of the type of heat treatment applied, i.e. direct heat or air drying followed by heat treatment."
>
> 4. "The biological performance shows the same trend found for the permanence properties, i.e. progressive deterioration as the temperature is increased, independent of the heat treatment applied at a specific temperature."
>
> 5. "The same sum of effects, possibly at a different level, will also be present for other inorganic salt preservatives. Thus CCB and ACC will also be likely to present similar durability problems after drying or heat treatment. In the case of ammonical copper arsenates similar effects may or may not exist."

From their findings they deduced that the effect of temperature drying on the biological performance of CCA-treated wood, at the chemical level are:

> "1) Conversion of the preservative chemicals into soluble components which then leach.

2) Conversion of the preservative chemicals into compounds which are biologically inactive.

3) Movement of the relative positions of reaction sites in the wood constituents to which CCA is "fixed"."

These studies raise important concerns for the preservative treating of wood composites. Heat-accelerated fixation could occur during pressing and thus possibly reduce both chemical diffusion and efficacy. To optimize efficacy, preservative-treated flakes might require complete drying at ambient conditions prior to board fabrication. If this is the case, then perhaps board durability of panels treated in this manner will surpass those in which the preservative has been added to the wax emulsion. These issues should be investigated.

1.4: Adding a Swelling Agent

Tri-n-butyl tin oxide was incorporated into beechwood using a swelling agent (diethylene dioxide plus 5% water) and a non-swelling agent (dry diethylene dioxide) (2). Samples were exposed to <u>Polystictus</u> <u>versicolor</u> for different lengths of time up to six weeks. Samples made using a swelling agent showed improved toxic effects. Possibly the preservative is better locked into the S_3/S_2 wall region rather than superficially deposited when a swelling agent is used, thus making the chemical more resistant to enzymatic attack (2). If waferboard is preservative-treated via pretreated flakes then perhaps a swelling agent can be found that improves fixation in susceptible cell wall regions.

1.5: Reducing Substrate Susceptibility and Preservative Treating

If wood could be treated in a way to reduce substrate susceptibility through nontoxic means, then less chemical should be necessary to insure adequate decay resistance (11). This probably will require a two or more step process in addition to normal fabrication steps. If this is true, then not only is fabrication more complex but also more expensive. Strength will more than likely be severely reduced. These would make this alternative less desirable.

1.6: Recommendations

Successful preservation of wood composites with wood preservatives requires that enough chemical be present to prevent attack by wood decaying organisms. If a chemical is to be added to waferboard via blending with wax, resin or wood furnish, it must be proven in less severe accelerated decay tests that sufficient chemical is present. Durability of these methods must be proven using different decay organisms. Strength reductions due to reduced resin bonding must be investigated. The exact influence on resin curing must be determined as well as costs due not only to the addition of preservative, but also to longer pressing times, increased processing and increased handling. For these methods to be successful, resin costs cannot be increased nor panel thickness to compensate for reduced strength. Preservative stability to high temperatures and pressures must be proven and preservative compatibility with plant processes (non-corrosive, low toxicity, non-combustible, non-irritating, easy to handle and contain) are also important factors for the success of each of these methods. If heat-accelerated fixation occurs during hot pressing then it must be determined if using pretreated, dried flakes will provide maximum preservative efficacy -- above that achieved with incorporation in resin, wax or wood furnish. Pretreating flakes may provide improved resistance to decay with the addition of a swelling agent (which increases preservative penetrability to susceptible cell wall regions).

From results discussed in this section, mixing preservative with wax appears to give the most encouraging results in terms of effectiveness and minimum strength losses. It is probably very useful to learn why addition of a preservative to resin appears to give inadequate results. Yet difficulties with wax-preservative compatibility must be eliminated and improved spray atomization developed. Reduced internal bond cannot be ignored. Success of wax - preservative incorporation requires minimization of strength losses especially those of internal bond strength. Powdered preservatives should be studied to determine if they can be mixed successfully with wax thereby providing an alternative to liquid preservatives. Another concern is the possibility of reduced penetration with sizing agents. Investigating these potential problems and concerns will improve preservative efficacy in treated wood composite panels.

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