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# Durability of pine strandboard modified with low molecular weight phenol formaldehyde

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# DURABILITY OF PINE STRANDBOARD MODIFIED WITH LOW MOLECULAR WEIGHT PHENOL FORMALDEHYDE

A Thesis

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## Table of Contents

## List of Tables

## List of Figures

## Abstract

A continuing challenge for wood and wood-based composite building materials has been durability--the power of resisting agents or influences which tend to cause changes, decay, or dissolution; lastingness. In the case of wood-based products, this often requires a resistance to biological degradation and moisture related dimensional instability (particularly in particle and flake or strand boards).

Borden Chemical Company has developed a new low molecular weight phenol formaldehyde additive, PD-112, to improve durability in composite wood products. This study investigated PD-112's contribution to durability in oriented strand board (OSB) through laboratory testing of treated southern pine strandboard panels versus untreated control panels. Tests examined mechanical properties, as well as resistance to degradation by water infiltration, mold, decay fungi and termite attack.

PD-112 treatment significantly reduced moisture induced thickness swelling without adverse effects on strength properties. Modulus of rupture (MOR) and modulus of elasticity (MOE) increased somewhat, while internal bonding strength (IB) increased greatly with increasing PD-112 treatment. PD-112 imparted good termite resistance to pine strandboard. Treatments gave excellent resistance to decay by selected brown rot fungi, and moderate resistance to growth of selected mold fungi.

## Chapter 1.

## Introduction

In the United States in 1998, production of plywood and oriented strandboard (OSB) were estimated at 15.73 and 9.94 million cubic meters, respectively (Sellers 2001). A major factor preventing OSB from replacing plywood in many commercial and residential structural applications is OSB's relative vulnerability to moisture infiltration—resulting primarily in dimensional change and strength loss. Changes in additives, processing, and adhesives may help solve the moisture problems plaguing OSB acceptance and expanded use. PD-112, a new low molecular weight phenol formaldehyde pretreatment, formulated by Borden Chemical Company is one such additive/adhesives ready for testing. A preliminary study commissioned by Roy O. Martin Company (Martco) and carried out by the Louisiana Forest Products Development Center (LFPDC) suggests that PD-112 has great potential as a commercial product (Smith 2002). If PD-112 makes a significant improvement in the strength, durability and dimensional stability of OSB under heavy moisture exposure conditions OSB may begin to compete with plywood on a more even basis. Determination of PD-112's effects on these properties is an important objective of this research.

Different types of wood-based composite panels use different types of adhesives, based primarily on the intended use of the panels. There are many types of wood composite panels available today, most of which are used in non-structural, indoor applications such as furniture components. Some of these include particleboard, hardboard, medium density fiberboard, and decorative plywood. Resins used in these products are often urea-formaldehyde (UF) and melamine-formaldehyde (MF). These resins are ideal for indoor and decorative applications because of their low cost and light color (making them less likely to discolor decorative panels). But UF and melamine resins do not form waterproof bonds, and so are unsuited to outdoor use (Sellers 2001). The predominant panels for outdoor and structural uses are plywood and OSB. Both OSB and plywood are most often produced using phenol-formaldehyde (PF) and polymeric methylene diphenyl diisocyanate (pMDI) resins. These resins, while more expensive to produce and utilize, offer greater resistance to moisture infiltration. In OSB manufactured using PF resin, moisture content and thickness swelling are closely related to mechanical (strength) properties. Studies have shown that while moisture content levels are closely related to mechanical properties, thickness swelling is a more effective predictor for these properties (Wu 1997)

Moisture infiltration leads to changes in dimensional stability and reduced strength and durability of panels. Much research has been done to determine acceptable levels of thickness swelling and linear expansion (dimensional stability) in the various wood-based panels. Under the PS-2-92 standard for OSB in the United States, a 25 percent maximum thickness swell is allowed after a three-week, one-side wetting cycle (Sellers 1998). A Canadian standard (Can. Std. 0437.0-93) allows a 15 percent increase for boards 12.7mm thick or less, and 10 percent for thicker boards after a 24-hour submersion (Smulski 1997). A 1996 report comparing swelling values between plywood and OSB of similar species composition shows the distance OSB must bridge to approach the effectiveness of plywood. After one year of outdoor exposure, OSB samples exhibited 11 percent to 18 percent thickness increase whereas the plywood swelled only 1 percent to 3 percent. A corresponding laboratory aging test done during the same study showed 34 percent to 46 percent thickness increase for OSB, and 2 percent to 3 percent for plywood (Okkonen and River 1996).

Biological degradation is another problem for OSB. Specifically, fungi (decay and mold) and termites can cause considerable damage to wood products. Reconstituted composite wood products are generally inherently less durable than solid wood products of the same species due to the fractured nature of the raw material. The processing of solid wood into furnish (chipping, grinding, flaking) increases the surface area exposed to attack and normal obstructions to moisture flow such as aspirated pits or tyloses are diminished. This allows easier access to moisture infiltration. Furthermore, OSB and similar panels are often made from less durable, lower density species such as aspen and pine (Morrell, 2001).

OSB is finding use in more challenging and hostile conditions with increasing market demand widespread use. With the withdrawal of chromated copper arsenate (CCA) from use in residential building materials in the United States, and the general unsuitability of composite products to pressure treatment, there is a need for an OSB treatment that can effectively resist biodeterioration by termites and fungi.

**Objectives**

The overall objective of this study was to investigate the potential contribution of PD-112 to durability of oriented strand board (OSB). More specifically:

- To evaluate PD-112's effect to enhance dimensional stability of OSB as it is exposed to moisture relative to an untreated control;

- To quantify the effect of various treatment levels of PD-112 additive on mechanical properties of OSB, including modulus of elasticity (MOE), modulus of rupture (MOR), and internal bonding strength (IB), and
- To evaluate PD-112's ability to provide resistance to biological degradation including attack by termites, mold, and decay fungi.

**Literature Review**

A study performed in 1991 investigated the use of a low molecular weight phenol-formaldehyde resin to improve particleboard (Kajita and Imamura 1991). In this study, particles of Japanese Cedar (*Cryptomeria japonica* D. Don) were impregnated with a phenol-formaldehyde additive at increasing levels, then incorporated into particleboards using a conventional phenol-formaldehyde adhesive. Impregnation was performed via three methods: A) dipping in the additive followed by a sprayed adhesive application, B) spraying the additive followed by a sprayed adhesive application, and C) spraying a mixture of the phenol-formaldehyde additive and conventional adhesive. This treated particleboard was subjected to tests of mechanical properties and biological degradation by fungi and termites. Kajita and Imamura found that modulus of rupture (MOR) increased somewhat with higher incorporated resin loading (IRL) for application method B, but showed no increase for methods A or C. MOR values for all IRL levels were in the general range of 4000 pounds per square inch (PSI) to 5000 PSI. Modulus of elasticity (MOE) were reported to increase with increased resin loading, with values ranging from approximately 420,000 PSI to 570,000 PSI. Internal bonding (IB) increased considerably with increased IRL for all application methods, from approximately 142 PSI to 280 PSI. Canadian standard CSA O437.O requires minimum

MOR values of 4200 PSI and 1800 PSI, MOE of 800,000 PSI and 225,000 PSI (parallel and perpendicular to face flake orientation, respectively) and IB of 50 PSI for OSB. The minimum allowable thickness swell after 24 hour soaking according to the Canadian standard is 15 percent for ½ inch thick or less boards, and 10 percent for boards thicker than ½ inch (Smulski, 1997). After water soaking and cyclic accelerated aging tests, with increased IRL, thickness swelling (TS) decreased for all application methods. Specimens with increased IRL experienced lower weight loss, for all treatment methods after 12 weeks exposure to soil inoculated with the decay fungi *Coriolus versicolor* and *Tyromyces palustris* (Japan Wood Preserving Association Standard 3-1979), and in a separate decay test involving burial in moist unsterile soil for nine months. Ten percent and 15 percent IRL treatments provided 100 percent protection from *Coriolus versicolor* in laboratory decay testing, versus approximately 30 percent weight loss for untreated (control) specimens. These same treatment levels gave approximately 90 percent to 100 percent protection from *Tyromyces palustris*. Formosan termite (*Coptotermes formosanus*) resistance also improved with increased IRL, for all treatment methods. In termite tests (JWPA Standard 12-1981), boards with specific gravity (SG) of 0.5 experienced approximately 15 percent weight loss for untreated, and less than 5 percent weight loss for 5, 10, and 15 percent IRL.

Kajita and Imamura suggested that low molecular weight PF resin treatment may impart greater biological resistance than conventional PF resin because larger conventional PF molecules are unable to occupy sites of potentially accessible regions within the wood structure. Low weight PF in aqueous solution may penetrate into cell walls more easily, rather than being trapped at lumen surfaces within the cell wall.

Until recently, Chromated Copper Arsenate (CCA) has been the preservative of choice for treating pine building materials, and is often used for comparison purposes in laboratory evaluations of termite and decay resistance. Grace (1998) tested the efficacy of CCA treated pine against Formosan subterranean termites. He treated solid pine wafers of 25 by 25 by 6 mm (1 by 1 by 0.25 in) to retentions of 0.6, 0.4, 0.2 and 0.1 pounds per cubic foot (pcf), and subjected these samples along with a group of untreated pine wafers (controls) to jars containing 150 g sand, 30 ml water and 400 Formosan subterranean termites for four weeks. He evaluated these samples with respect to termite mortality (percent), weight loss (percent) and visual rating using a scale of 0 to10 (0 indicated total sample failure, and 10 indicated no damage). Grace found that CCA levels as low as 0.1 pcf reduced weight loss from 35.61 percent for untreated samples to 0.72 percent. For all CCA treatment levels, termites experienced 100 percent mortality, and the lowest visual rating for any CCA treated group was 9. The control group showed an average rating of 3.2, with 29.20 percent mortality.

Mitchoff and Morrell (1988) investigated decay resistance of red alder (*Alnus rubra*) treated with CCA, along with copper 8 quinolinolate, zinc naphthenate (ZN) and thiocyanomethylthiobenzothiazole (TCMTB), compared to untreated (control) alder samples. These specimens were placed in jars containing soil inoculated with *Coriolus versicolor, Gloeophyllum trabeum*, and *Poria placenta*. Samples were removed after 16 weeks exposure to the fungi. CCA provided the greatest protection to the alder samples, for all fungi tested. Following *P. placenta* exposure, CCA at 1.1 kg/m$^3$ reduced weight loss to approximately 2 percent from approximately 50 percent for untreated samples. Similar results were obtained from *G. trabeum* testing—1.0 kg/m$^3$ CCA samples experienced approximately 3 percent weight loss compared to 60 percent for untreated samples.

Jeihooni et al. (1994) compared the decay resistance of Douglas fir flakeboard treated with CCA, borate and azaconazole. Flakes were pretreated with CCA to target concentrations of 2.4, 6.4, and and 9.6 kg/m$^3$, and borate treated to target concentrations of 0.20 percent, 0.33 percent and 0.67 percent boric acid equivalent (BAE). Flakes were made into panels 305 by 305 by 13 mm, and samples were cut from these boards and subjected to the decay fungi *Postia* placenta in accordance with American Wood Preservers Association's (AWPA) standard E10-91. Comparisons were based on percent weight loss experienced by test specimens. Untreated (control) specimens experienced 50.30 percent weight loss. The CCA samples at 2.40 kg/m$^3$, 6.40 kg/m$^3$ and 9.60 kg/m$^3$ target retention experienced 1.93 percent, 1.58 percent and1.24 percent weight loss, respectively. The borates did not perform quite as well, with weight loss of 1.97 percent, 3.06 percent and 3.70 percent for BAE levels of 0.20 percent, 0.33 percent and 0.67 percent, respectively.

Removal of CCA has left a gap in the residential building materials market for biologically durable, environmentally safe wood products. Use of borates to combat degradation by insects and fungi has shown promise, but effectively incorporating borates into composite panels has proven challenging due to borates' interference with adhesives commonly used in panel products. Several studies have been carried out to determine the efficacy of borates against biodeterioration.

Zinc borate (ZB) has shown effectiveness at preventing or reducing mold growth on several types of building construction materials at boric acid equivalent (BAE) levels of 0.40 percent to 1.76 percent. ZB at BAE levels above 1.00 can also provide adequate protection from termites and decay when used in medium density fiberboards without adversely affecting physical or mechanical properties (Fogel and Lloyd, 2002; Tsunoda et al. 2002). Fogel and Lloyd (2002) found that 1.76 percent boric acid equivalent (BAE) reduced mold growth on aspen OSB after four weeks exposure from a rating of 3.0 (moderate growth) for the control group to a rating of 1.0 (traces of growth) for treated samples. Zinc borate, at a concentration of 1.00 percent BAE also resulted in a reduction in weight loss to termites from 18.0 percent in untreated radiata pine MDF to 0.9 percent, as reported by Tsunoda et al. (2002).

The use of an organic flowing agent, polyethylene glycol (PEG) has been investigated to determine its effectiveness at reducing the negative effect of borates on panel adhesion. In one study, the incorporation of PEG with ZN at BAE levels of 1.0, 2.5, and 5.0 percent caused an increase in MOR and IB values, but showed a decrease in MOE values (Sean, et al. 1999). PEG decreased TS, and effectively prevented degradation by fungi and termites.

In a laboratory trial, Lee et al. (2004) evaluated the effectiveness of calcium borate (CB) and zinc borate (ZB) for protection of OSB made from southern pine and southern mixed hardwood species. The mixed hardwood boards consisted of ash (*Fraxinus* spp.), cottonwood (*Populus* spp.), cypress (*Taxodium distichum*), elm (*Ulmus* spp.), locust (*Ribinia psdudoacacia*) pecan (*Carya* spp.) and red oak (*Quercus* spp.). Boards were treated to BAE levels of approximately 1 percent to 3 percent, and subjected to the AWPA E1-97 laboratory test for termite resistance. For both panel types (pine and hardwood) treated with ZB, there were no significant differences among the treated groups with respect to sample weight loss or termite mortality at the $p = 0.05$ level. The treated samples did differ significantly from the untreated (control) group, however. Control samples lost an average of 16.48 percent and 21.02 percent of their original weight for hardwood and pine. The treated samples had weight loss of approximately 4 percent and 3 percent for hardwood and pine, respectively. Results were similar with CB. Hardwood and pine control groups experienced weight losses of 21.32 percent and18.99 percent, respectively while the treated groups had weight losses of approximately 5.5 and 4.5 percent for hardwood and pine, respectively.

Green blending of wood furnish to be used in OSB production has been investigated as a viable way to obtain effective diffusion of water borne preservative treatments (Edwardson, 2001). Green blending is the process of adding chemicals to wood furnish that has high moisture content (typically above 30 percent moisture, dry wood basis), then allowing time for the chemical to diffuse into the wood. Edwardson identified three factors to consider when green blending: moisture content, fines content and temperature. Moisture content of the furnish must be closely monitored in order for proper application rates to be achieved. If screened out after the green blending process, fines may present a waste disposal challenge, depending on the nature of the chemical applied. Additionally, fines may absorb more of the chemical, requiring greater application rates to meet target loading. Lastly, temperature of the treating solution must be considered, as it can affect diffusion of the treatment chemical through wood. Edwardson tested three-layer, ½ inch thick aspen OSB panels treated with a liquid borate product at 12, 15, 18, and 25 percent loading (on a weight-to-weight basis using oven-dry weight of wood strands). The panels were bonded with liquid isocyanate resin (MDI).

Physical property testing revealed the panels met industry standards, with: IB >50 PSI, MOR >4,000 PSI, MOE >800,000 PSI.  Twenty four hour water soaking produced water absorption (WA) and edge swelling (ES) values of <30 percent  and <20 percent, respectively.

It is unknown how PD-112, a new specially formulated phenol formaldehyde additive, will affect strandboard properties when used in conjunction with green blending practices.  This study subjected PD-112 modified pine strandboard to tests of strength, dimensional stability, termite resistance, mold resistance and fungal decay resistance.

# Chapter 2.

## Manufacture of Test Panels

Panel manufacturing consisted of four basic steps: preparation and PD-112 treatment of furnish, addition of resin and wax, mat formation, and pressing. Panels were manufactured under conditions that approximated industrial manufacturing as closely as feasible. These processing conditions were obtained from a local OSB manufacturer.

### Materials and Methods

Four target levels of PD-112 application or content were investigated for each test. These consist of 0 percent (control), 10 percent, 20 percent, and 30 percent PD-112 resin solids by oven dry weight of wood. Three layer southern yellow pine strandboard panels consisting of face flakes throughout were made with 3.5 percent phenol-formaldehyde (PF) resin and 1 percent wax (solids content based on oven dry wood weight). PF resin was used in all panels. The three layer panels consist of two face layers (front and back surface) and a core layer (center). The face layers each contained 30 percent of the total untreated furnish (per board, oven-dry weight basis), while the core layer contained the remaining 40 percent.

The PF resins used in the face and core layers contained 45 percent and 47 percent solids by weight, respectively (i.e. the face resin contained 45 percent PF solids, and 55 percent liquid carrier), the wax contained 45 percent solids, and the PD-112 resin contained 35 percent solids, by weight. After PD-112 treatment, and application of resin and wax, flakes were hand-laid into a forming box measuring 50.8 cm by 57.15 cm (20 in by 22.5 in). Flakes were laid into the forming box without regard to orientation (i.e., randomly). Panels were pressed to 1.27 cm (0.5 in) at a platen temperature of 200$^{o}$C and a pressure of 181,437 kg (200 tons). Press platens are 60.96 cm by 60.96 cm (24 in by 24 in), producing usable 45.72 cm by 50.8 cm (18in by 20 in) panels after discarding material for edge effects. Target oven dried panel density was 0.67 g/cm$^3$ (42 lb/ft$^3$). Three panels were manufactured for each treatment level. In order for all panels to have the same density, as PD-112 composition increases, furnish weight must decrease. This required the amounts of material, per panel based on the different levels of PD-112 treatments shown in table 1.

**Table 1. Components of test panels, per treatment. Wax, resin and PD-112 weights are expressed as total weights (i.e. solids plus carrier). All weights are expressed in grams.**

| PD-112 Treatment Level (%) | Wax | PF Resin | PD-112 | Furnish (o.d.wt,) |
|---|---|---|---|---|
| 0% | 70.6 | 246.96 | 0 | 3032.26 |
| 10% | 70.6 | 246.96 | 907.18 | 2714.75 |
| 20% | 70.6 | 246.96 | 1814.4 | 2397.23 |
| 30% | 70.6 | 246.96 | 2721.6 | 2079.72 |

Treatment of Furnish

Flakes were obtained from Weyerhaeuser's Ruston, LA OSB plant and transported to the Louisiana Forest Products Development Center, where they were stored in plastic bags until panel manufacturing began. The furnish was retrieved from the plastic bags, and its moisture content determined. The oven-dry weight was calculated and used as the basis for determining the amount of water to add to bring the furnish to the desired moisture content.

Water was added to the flakes to bring the moisture content to between 30 and 50 percent before PD-112 was applied. Water was added using the LFPDC's resin blending apparatus, consisting of a rotating drum measuring 121.92 cm (48 in) in diameter and

54.61 cm (21.5 inches) in depth. Two Cole-Parmer Masterflex tubing pumps each deliver liquid to a Spraying Systems Company ¼ JAC air atomizing nozzle. An air compressor delivers air to the spray nozzles, and a portable support apparatus positions the nozzles in the rotary drum. After water was added to the furnish, moisture content samples were again taken to assure target moisture content values had been reached. The calculated oven-dry furnish weight value from the previous step was used to determine appropriate PD-112 application rates to achieve target treatment levels.

Once target moisture content levels were reached, PD-112 was applied to the wet furnish using the resin blender. For water and PD-112 application, air flow rate to the nozzles was approximately 18.41 liters per minute (l/min), liquid flow rate was approximately .00044 l/min and the rotational rate of the drum was 11.25 RPM. After treatment, the flakes were dried in a lumber kiln to between approximately 3 percent and 5 percent moisture content.

### Application of Resin and Wax

Furnish was segregated by weight into face and core layers and put into the resin blender, where resin and wax were applied simultaneously at the same rate as the PD-112 application. Face and core layers were blended separately, with 45 percent PF resin applied to face furnish and 47 percent PF applied to core furnish. Target resin content was 3.5 percent by oven-dry weight of treated furnish for both the face and core layers, and target wax content was 1 percent by oven-dry weight of treated furnish.

### Panel Layout

After resin and wax was applied to the furnish, the forming box was placed atop a 60.96 cm by 60.96 cm (24 inch by 24 inch) solid caul. A face layer of flakes was first laid out onto the caul without regard to flake alignment (random orientation). Care was taken to ensure flakes were placed uniformly within the box. The core layer was laid outon top of the first face layer in the same fashion, followed by the second face layer.

Pressing

The forming apparatus (caul, flake mat and forming box) was placed on the feed tray of the Wabash laboratory hydraulic press. The forming box was removed and 0.5 inch thick steel spacing bars were placed on either side of the caul, next to the mat. A second caul was placed on top of the mat, and the apparatus was fed into the press. The press was closed under 181436.9 kg (200 tons), at a platen temperature of 200$^{o}$C. After two minutes the press was opened over the course of 45 seconds, to gradually relieve steam pressure. The finished panel was then allowed to cool overnight.

**Results**

Pre-Treatment with PD-112

Treated flakes were sent to Borden Chemical Company's analytical laboratory in Springfield, Oregon for analysis of PD-112 content. Target PD-112 levels and their corresponding actual levels can be seen in Table 3. Table 4 shows oven dry density for panels at various PD-112 levels.

**Table 2. Target and actual PD-112 levels.**

| Target PD-112 Level | Actual PD-112 Level |
|---|---|
| 0% | 0% |
| 10% | 10.06% |
| 20% | 17.47% |
| 30% | 22.69% |

**Table 3. Actual panel density at ovendry condition**.

| Treatment | Density (g/cc) |
|---|---|
| 0% | 0.72 |
| 10% | 0.72 |
| 17% | 0.76 |
| 23% | 0.81 |

# Chapter 3.

## Mechanical Properties and Dimensional Stability

### Materials and Methods

Standard Test Methods for Mechanical Properties of Lumber and Wood-Based Structural Material (ASTM D 4761-93) was used to determine MOR and MOE of the manufactured test boards. Nine samples were prepared at each PD-112 level (total 36 samples) for each of these tests.

Modulus of Rupture (MOR) and Modulus of Elasticity (MOE)

Modulus of Rupture is a measure of the bending strength of a sample under a load. Modulus of elasticity is the ratio of stress applied to a sample to the strain experienced as a result of that stress. In other words, MOE measures the resistance of a body to deformation under load. MOR measures strength, while MOE measures stiffness (Haygreen and Bowyer 1996). Three inch by four inch specimens were placed into the LFPDC's Instron test apparatus, on a fixed support with a span of 30.48 cm (12 inches). The samples were then loaded to failure, with MOR and MOE data reported by the Instron's output device.

MOR of a rectangular specimen supported on both ends and loaded at the span center is calculated from the equation:

$$MOR = 1.5PL/bd^2 \text{ (psi)}$$

where

P = the breaking (maximum) load in pounds
L = the distance between supports (span) in inches
b = the width of the beam in inches
d = the depth of the beam in inches.

MOE of a similar specimen is calculated from the equation:

$MOE = PL^3/48ID$ (psi)

where

P = the concentrated center load in pounds (below the proportional limit)
D = the deflection at midspan in inches resulting from P
L = the span in inches
I = the moment of inertia in inches.

<u>Internal Bonding (IB)</u>

Internal Bonding is the strength in tension perpendicular to the plane of the panel (Haygreen and Bowyer, 1996). Two inch by two inch specimens were prepared by gluing to aluminum fixtures using hot melt adhesive. The specimens were placed into grips in the Instron test apparatus, and tension was applied until specimen failure. IB data were reported by the Instron's output device. Internal bonding is calculated by dividing the load to failure by the surface area of the specimen.

<u>Submersion Test for Dimensional Stability</u>

A standard test for water absorption and thickness swelling (ASTM D 1037) was used to test dimensional stability. Five test specimens six inches by six inches were tested for each treatment combination (20 total samples). Samples were conditioned to constant weight and moisture content in a chamber maintained at 65 percent relative humidity, and $20^{o}$ C. Moisture content and weight was recorded to 0.2 percent. Moisture content was determined by oven-drying samples upon test completion, then comparing initial weight to oven-dry weight. Thickness was measured using a digital micrometer at four points midway along each side, 2.54 cm (one inch) from the edge and at the center. Thickness was recorded to an accuracy of +/- 0.3 percent.

The specimens were submerged horizontally under 2.54 cm (1 in) of water for two hours. Specimens were removed and after excess water was wiped off, suspended vertically and allowed to drain for 10 minutes. Specimens were measured, weighed, and re-submerged for an additional 22 hours. After 22 hours, specimens were again removed, weighed, measured and oven-dried. Moisture content was calculated from the weights obtained before testing and after submersion.

**Results and Discussion**

Mechanical Properties

Test panels were constructed without regard to flake orientation (i.e. randomly oriented). This construction scheme was chosen to simplify manufacturing, as this study focused most heavily on testing of biological durability and dimensional stability. Emphasis was placed on proper and uniform PD-112 treatment, possibly at the expense of physical properties such as strength and stiffness. Because of these situations, untreated panels may not exhibit physical properties that would be expected of oriented flake panels.

Average sample density (ovendry), MOR, MOE and IB are shown in Table 4. Although in general, higher board density gives greater strength (Haygreen and Bowyer, 1996), there appears to be no definite relationship between the two with respect to MOR and MOE as shown in Table 4. Sample density increases from 0.72 $g/cm^3$ for the 0 percent PD-112 group to 0.76 $g/cm^3$ for the 17 percent PD-112 group, while the MOR and MOE values for the respective treatment groups exhibited no significant change.

**Table 4. Summary of mechanical properties of treated strandboards. Included are treatment level, density, MOE, MOR, and IB. Means sharing a capital letter do not differ at the α= 0.05 level according to Duncan's Multiple Range Test in SAS 9.0.**

| | Density | MOE | MOR | IB |
|---|---|---|---|---|
| Treatment | g/cc | Mpa | Mpa | kPa |
| 0% | 0.72 **A** | 4435.80 **A** | 29.93 **A** | 102.74 **A** |
| 10% | 0.72 **A** | 5156.48 **B** | 33.97 **A** | 399.95 **B** |
| 17% | 0.76 **B** | 5143.65 **B** | 30.34 **A** | 719.06 **C** |
| 23% | 0.81 **C** | 6535.23 **C** | 47.47 **B** | 2150.00 **D** |

The increase in density from 0.76 g/cm$^3$ to 0.81 g/cm$^3$ for the 17 percent and 23 percent PD-112 groups does, however, correspond to significant increases in MOE, MOR and IB. Density variations likely had an influence on the strength properties of tested panels, considering the relationship between density and strength (Haygreen and Bowyer, 1996).

Figure 1 shows the effect of various PD-112 levels on modulus of rupture (MOR). The MOR of treated panels did not increase significantly from the control group at PD-112 levels of 17 percent and below. However, a threshold appears to emerge above the 17 percent PD-112 level. At the 23 percent level, MOR showed an increase of at least 13.79 MPa (2,000 psi) over the greatest of the other group means (23 percent ≈ 47.47 MPa (6,885 PSI); 10 percent ≈ 33.98 MPa (4,928 PSI). As Kajita and Imamura speculated, this general lack of response to increasing PD-112 exhibited by the MOR values may result from decreased compression in the treated boards during manufacturing. At constant board density, the amount of wood furnish decreases with increasing resin loading. The lack of orientation in the test panels (random flake alignment) may also contribute to the lack of predictable response with respect to MOR and MOE, as bending strength is closely related to flake alignment. For instance, Wu (1997) showed that for an OSB panel with "high flake alignment" (82.3 percent alignment) MOR and MOE values differed drastically when tested parallel and

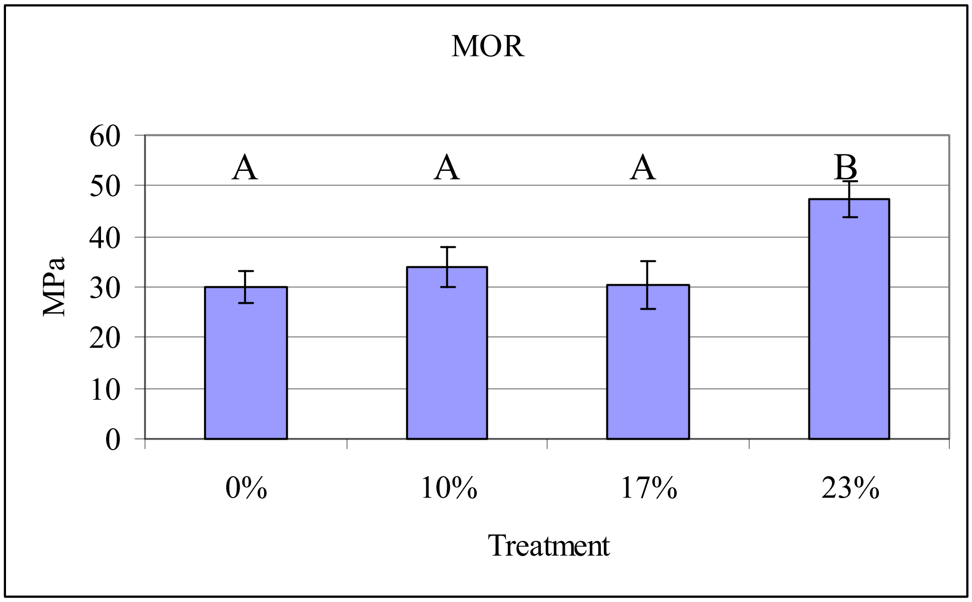


**Figure 1. Effect of PD-112 on MOR, expressed in MPa. Vertical error bars represent 95% confidence interval around mean. Means sharing capital letter do not differ at α = 0.05 according to Duncan's Multiple Range Test in SAS 9.0.**

perpendicular to the axis of face flake orientation. Testing parallel to the flake direction yielded MOR and MOE values of 8.91 and13.65 times the perpendicular values, respectively. The parallel values for a "randomly aligned" (5.2 percent flake alignment) panel for MOR and MOE were 0.77 and 0.86 times the perpendicular values, respectively.

Modulus of elasticity (MOE) values for treated panels increased gradually from the untreated control group to the 23 percent group, as seen in Figure 2. The 10 percent and 17 percent groups, although not significantly different from each other, exhibited MOE values significantly greater than the untreated group. The 23 percent group had significantly higher MOE values than all of the other groups. As with MOR, a threshold appears between the 17 percent PD-112 and 23 percent PD-112 treatment levels. The random flake alignment of the test panels may also have an influence on MOE values.

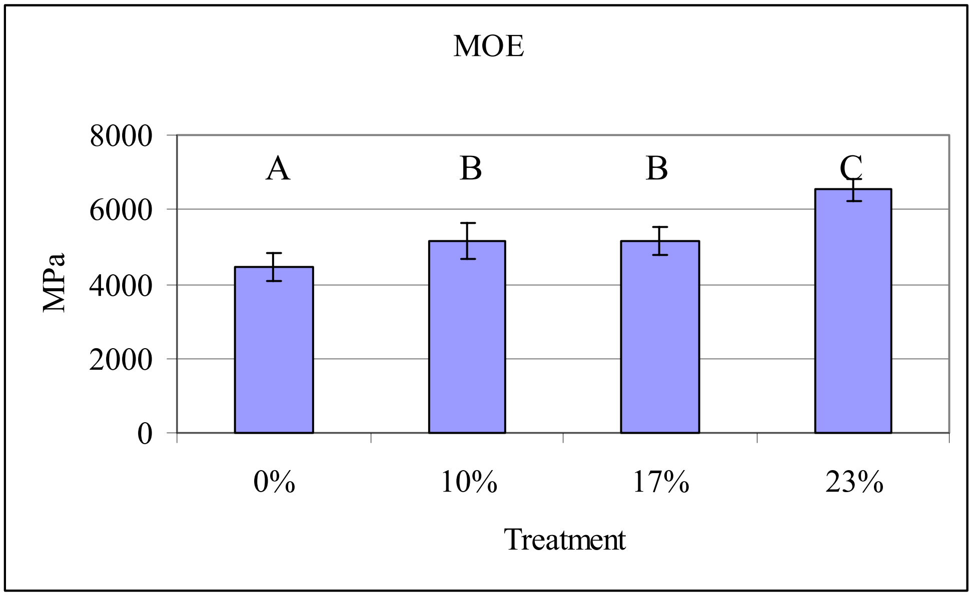


**Figure 2. Effect of PD-112 on MOE, expressed in MPa. Vertical error bars represent 95% confidence interval around mean. Means sharing capital letter do not differ at α = 0.05 according to Duncan's Multiple Range Test in SAS 9.0.**

The treated panels exhibited a much more dramatic increase in internal bonding strength (IB) over the untreated controls than was observed with MOR or MOE, as shown in Figure 3. Addition of 10 percent PD-112 caused an increase of approximately 303 kPa (44 PSI) over the control group, 17 percent increased 613 kPa (89 PSI), and 23 percent PD-112 caused an increase in IB of approximately 20 times that of the control group (from 103 kPa to 2150 kPa). Again, we see a more dramatic increase between the 17 percent and 23 percent PD-112 groups than between the 17 percent and 10 percent groups or the 10 percent and untreated groups. This also points toward a threshold existing between the 17 percent and 23 percent PD-112 levels. IB strength should not be affected by strand orientation, or lack thereof, as IB is a measure of the strength of the board across its thickness (irrespective of length or width), or the strength of adhesive bonds between strands.

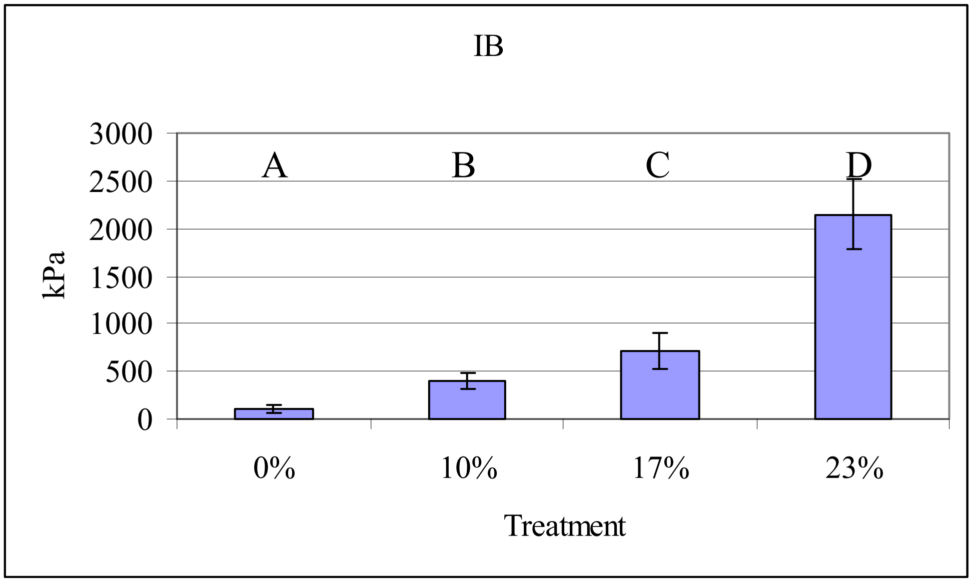


**Figure 3. Effect of PD-112 on IB, expressed in kPa. Vertical error bars represent 95% confidence interval around mean. Means sharing capital letter do not differ at α = 0.05 according to Duncan's Multiple Range Test in SAS 9.0.**

Some glue failures were encountered during testing for internal bonding strength. These failures occurred in the adhesive bond between the test specimen and the aluminum testing fixtures, exclusively during testing of the 23 percent PD-112 group. A typical glue bond failure, next to a proper sample failure, is shown in Figure 4. The failures occurred most often at pressures greater than 1378 kPa (200 PSI), but in some instances at pressure as low as 496 kPa (72 PSI). That the adhesive failed only on the 23 percent group, even at pressures experienced by the 17 percent group suggests that at high concentration treated panels may have an aversion to hot-melt adhesives. Any separation between the test specimen and the test fixture (if metal was visible on the bonding surface of the fixture after sample failure) was considered a glue failure and that specimen was discarded. In the case of a discarded specimen, a new specimen from the same panel was prepared and tested in replacement of the discarded specimen.

**Figure 4. IB glue bond failure. Block at left has shows approximately 60 percent adhesive failure. Block at right shows proper adhesion and sample failure.**

24 Hour Thickness Swelling

Figure 5 shows the average percent thickness swelling experienced by all treatment groups after a two hour water submersion, then additional 22 hour submersion (24 hour total submersion time). Values shown in this figure are an average of all measurement points across the specimen, without regard to its relationship to the center or edge of the specimen. For both the two hour and 24 hour submersion times, three significantly different groups emerged with respect to panel thickness swell. The 10 percent and 17 percent groups, while statistically similar, showed considerably less swelling than the control group; the 23 percent group swelled much less than any other group. After two hours submersion time, the swelling experienced by the control group was approximately twice that of the 10 percent group, three times that of the 17 percent group, and more than 10 times that of the 23 percent group. The increased resin loading has substantially reduced panel swelling, from total board swelling of 55.93 percent for the control group to 24.68 percent for the 10 percent group following 24 hour submersion. Total board swelling for the 23 percent group was 4.97 percent after 24 hour submersion. Tables 4 and 5 summarize panel swelling values for two hour and 24 hour submersion.

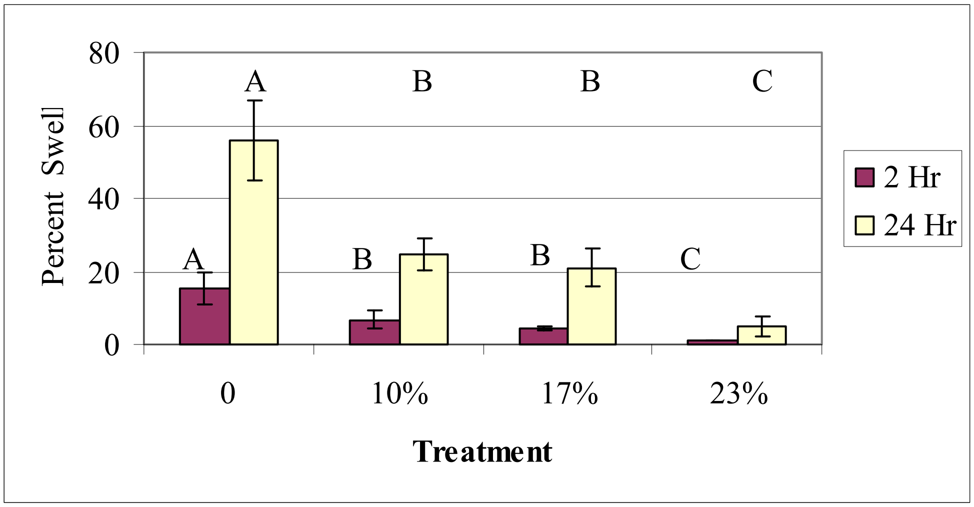


**Figure 5. Percent swelling, all groups. Vertical error bars represent 95% confidence interval around mean. Means sharing capital letter do not differ at α = 0.05 according to Duncan's Multiple Range Test in SAS 9.0.**

Figure 6 shows the swelling rates for the center and edge regions of the test panels. These values are displayed for 24 hour submersion times. Untreated control panels exhibited considerable swelling. Total average swelling for the control group was 55.93 percent. As expected, the center swelled less than the edge, presumably due to a greater water infiltration rate through the edge (between flakes) than through the surface of the board.

In Figure 6, swelling rates for the 10 percent PD-112 group are seen to exhibit the same general trend as the control group, as the swelling is greater at the measurement points along the edge of the board than in the center. At the center measurement point, however, the 17 percent PD-112 group exhibited greater swelling than the 10 percent PD-112 group. This anomaly may have resulted from one or both of two circumstances: a folded flake at or near the center measurement point on a specimen from the 17 percent

**Table 5. Summary of thickness swelling percentages exhibited by PD-112 treated strandboards after two hour water submersion. Standard deviations are in parentheses.**

| | Panel Region | | |
|---|---|---|---|
| PD-112 Treatment (%) | Center | Edge | Average |
| 0 | 13.37 (1.50) | 15.59 (4.07) | 15.15 (3.56) |
| 10 | 4.23 (2.50) | 7.37 (2.43) | 6.74 (2.30) |
| 17 | 5.44 (1.90) | 4.34 (0.51) | 4.56 (0.61) |
| 23 | 1.12 (0.32) | 1.10 (0.21) | 1.10 (0.17) |

PD-112 group that may have "sprung back" during the submersion process causing an artificially inflated swelling value for that measurement; another possibility is that a specimen in the 10 percent PD-112 group had a higher concentration of resin at or near the center measurement point, causing an abnormally low swelling reading. These phenomena may be among the reasons that the 10 percent PD-112 group and the 17 percent PD-112 group did not differ significantly at the $\alpha$=0.05 level. The increased resin loading has resulted in a major decrease in thickness swelling for the center and edge regions. The 23 percent PD-112 has reduced center thickness swelling by 92.22 percent

**Table 6. Summary of thickness swelling percentages exhibited by PD-112 treated strandboards after 24 hour water submersion. Standard deviations are in parentheses.**

| | Panel Region | | |
|---|---|---|---|
| PD-112 Treatment (%) | Center | Edge | Average |
| 0 | 54.85 (9.78) | 56.20 (8.55) | 55.93 (8.67) |
| 10 | 22.00 (5.30) | 25.35 (4.25) | 24.68 (4.32) |
| 17 | 22.62 (5.88) | 20.66 (4.91) | 21.05 (5.03) |
| 23 | 4.27 (2.45) | 5.14 (2.86) | 4.97 (2.75) |

over controls (54.85 percent swelling for control group, 4.27 percent swelling for 23 percent PD-112 group) and has reduced edge swelling by 90.85 percent (56.20 percent swelling versus 5.14 percent swelling).

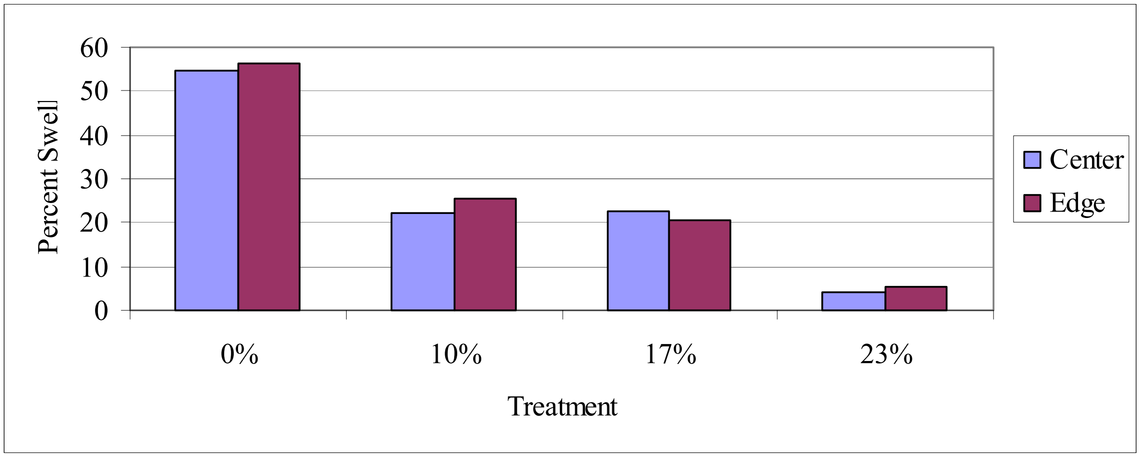


**Figure 6. Percent swelling of treated strandboards at panel center and edge after 24 hour water submersion.**

Swelling values for samples after two hour submersion are shown in Figure 7. For the untreated (control) group, the center and edge regions swelled 13.37 percent and 15.59 percent, respectively. After two hour submersion, the center and edge regions of the 10 percent PD-112 group swelled 4.23 percent and 7.37 percent, respectively. Center thickness swelling after two hours submersion was for the 17 percent PD-112 group was 5.44 percent. The incorporation of 23 percent PD-112 reduced the center thickness swelling by 91.62 percent over the control group (13.37 percent swelling for controls, 1.12 percent swelling for 23 percent PD-112) and reduced edge swelling by 92.94 percent (15.59 percent swelling for controls, 1.10 percent swelling for the 23 percent PD-112 group).

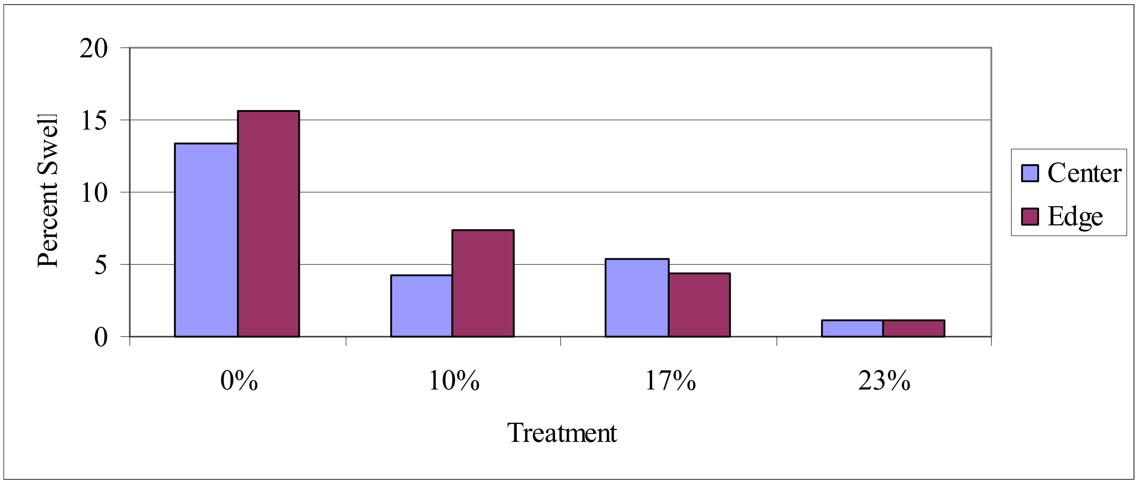


**Figure 7. Percent swelling of treated strandboards at panel center and edge after two hour water submersion.**

**Conclusions**

Mechanical Properties

Mechanical properties measurements included modulus of rupture (MOR), modulus of elasticity (MOE) and internal bonding (IB). An oft cited standard outlining the minimum allowable values for these measures in structural panels is Canadian standard CSA O437.0. This standard describes MOR and MOE in two separate categories: parallel to the primary face flake direction and perpendicular to the primary face flake direction. Due to the nature of OSB, MOR and MOE values are significantly greater when tested parallel to flake direction than perpendicular. Due to the randomly aligned design of the test panels in this study, MOR and MOE values obtained in testing cannot be compared directly to CSA O437.0. MOR and MOE for treated panels in this study should be compared primarily to those of the untreated (control) panels. It should be noted, however, that MOR values for untreated panels met the CSA requirement for testing parallel to flake direction of 28.96 MPa (4,200 psi). The only treatment group that significantly improved MOR for all panels tested was 23 percent PD-112 with an average

MOR of 47.47 MPa (6,885.32 psi). For MOE, untreated panels met the CSA perpendicular requirement of 1551.32 MPa (225,000 psi), but fell short of the parallel standard of 5515.81 MPa (800,000 PSI) with MOE of 4435.80 MPa (643,358 PSI). Twenty-three percent PD-112 increased MOE to 6,535.23 MPa (947,855psi), meeting the parallel requirement. With respect to IB, untreated panels did not meet the CSA requirement of 344.74 kPa (50 psi), averaging only 102.73 kPa (14.90 psi). Addition of PD-112 to 10 percent pushed IB to approximately 400 kPa (58.00 psi), meeting CSA standards. Twenty three percent PD-112 dramatically increased IB to 2,150 kPa (311.83 psi).

PD-112 improved strength characteristics of the strandboard tested. MOR and MOE were improved only slightly at the 10 percent and 17 percent levels, with 23 percent treatment giving the greatest increase in strength. IB improved steadily with increasing PD-112, but also experiencing the greatest progress between 17 percent and 23 percent PD-112.

<u>Dimensional Stability</u>

CSA O437.0 allows for 15 percent thickness swelling in 1.27 cm (0.5 inch) OSB after 24 hours submersion in water. Untreated panels did not meet the standard, with average swelling of 55.93 percent, but 10 percent PD-112 reduced swelling by more than half, to 24.68 percent. Increasing PD-112 content to 23 percent PD-112 further reduced thickness swelling to 4.97 percent. Jeihooni et al. (1994) found that increasing CCA and borate loadings in Douglas-fir flakeboards resulted in greater thickness swelling after six weeks exposure to high humidity conditions. Although these results cannot be compared directly to 24 hour submersion results, they suggest a trend towards increased moisture induced damage with increased preservative treatment. Results from PD-112 testing indicate a reversal of that trend.

## Chapter 4.

## Termite Resistance

### Materials and Methods

The Formosan subterranean termite test consisted of a single choice laboratory test to determine efficacy. This test is described in American Wood-Preservers' Association Standard E1-97.

#### Termite Collection

Subterranean Formosan Termites (*Coptotermes formosanus*) were collected from Sam Houston Jones State Park in Lake Charles, LA using a modified "bait crate" collection apparatus. This consisted of a plastic milk crate containing rolled cardboard buried just beneath ground level near an actively foraging termite colony. The crate was removed after approximately six weeks and transported to the LFPDC termite laboratory, where the termites were extracted. Termites remained in the bait crate from the collection date of February 6, 2004 until their extraction and use on February 9, 2004.

#### Test Setup

Sample preparation included five samples of each formulation and five samples of clear southern yellow pine sapwood cut to one 2.54 cm by 2.54 cm (inch by one inch) squares, each with a paired sample for moisture content determination. Moisture contents for test specimens were calculated by weighing each specimen alongside its paired moisture content (MC) sample. Test specimens and corresponding MC samples were allowed to equilibrate under the same environmental conditions, to ensure similar moisture contents. The MC sample was then oven dried and reweighed. The oven dried value was used to calculate the moisture content of the MC sample and test specimen at the time of initial weighing. This moisture content was then used to calculate the oven dried weight of the test specimen, without actually oven drying it. This method was used to avoid driving off volatile chemicals contained in the test specimen prior to termite exposure.

Test jars were prepared by adding 150 grams of sterilized number four (fine) blasting sand and 30 grams of distilled water then allowed to sit for two hours to ensure even water distribution throughout the sand. Test specimens were placed in the jar on a one inch square piece of aluminum foil (to prevent potential chemical leaching into the sand) with two corners of the specimen in contact with the jar wall.

A sample of 500 termites was weighed after extraction. Average weight per termite was calculated; from this calculation, 400 termites (by weight) were added to each jar.

## Evaluation

After four weeks, specimens were removed from the test jars. Surviving termites were counted to determine mortality rate; specimens were oven-dried, weighed and visually evaluated on a scale of 0 to 10. The visual evaluation was based on a rating system including the following landmarks:

| | |
|---|---|
| 10 | Sound, surface nibbles permitted |
| 9 | Light attack |
| 7 | Moderate attack, penetration |
| 4 | Heavy attack |
| 0 | Failure |

Reported data included visual rating of each block, change in dry mass, percentage change in dry mass, number of live workers, number of live soldiers, and percentage of mortality.

**Results and Discussion**

Table 7 summarized results obtained from termite testing. It shows percent weight loss due to termite attack, percent termite mortality throughout the duration of the test, and sample visual rating according to the scale of 0-10. Values in parentheses represent standard deviations.

**Table 7. Summary of results from testing of treated panels in four week no-choice termite jar test. Shown are treatment level, percent weight loss, percent termite mortality, and sample rating. Values in parentheses are standard deviations.**

| Treatment | Percent Weight Loss | Percent Mortality | Sample Rating |
|---|---|---|---|
| Solid Pine Control | 29.00 (1.79) | 21.86 (6.47) | 0.33 (0.56) |
| 0% PD-112 | 17.32 (1.52) | 21.91 (3.60) | 3.87 (1.00) |
| 10% PD-112 | 6.10 (0.59) | 99.30 (1.57) | 7.00 (0.63) |
| 17% PD-112 | 7.13 (1.62) | 90.20 (20.28) | 7.60 (0.48) |
| 23% PD-112 | 4.54 (0.72) | 94.66 (11.94) | 8.60 (0.50) |

Percent mortality of the termites in test containers for all treatment groups is shown in Figure 8. Two significant groupings emerged: group A consisted of the three treated groups and group B consisted of the two untreated controls. In the treated group, 10 percent PD-112, 17 percent PD-112 and 23 percent PD-112 treatments caused 99.30 percent mortality, 90.20 percent mortality, and 94.66 percent mortality, respectively. Average mortality for this group was 94.72 percent. In the untreated group, the solid pine control yielded a termite mortality of 21.86 percent. The strandboard control yielded a termite mortality of 21.91 percent. Average mortality for this group was 21.89 percent. The low termite mortality for the untreated control group is evidence that the test was carried out under conditions favorable to termite survival. This suggests that there were no other factors at work to reduce termite vigor.

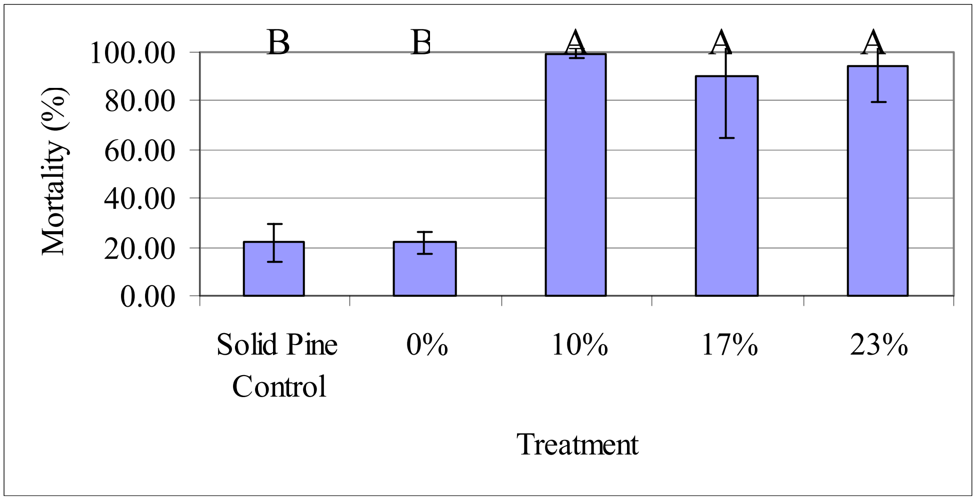


**Figure 8. Percent termite mortality for all treatments after four weeks in no-choice jar test. Vertical error bars represent 95% confidence interval around mean. Means sharing capital letter do not differ at α = 0.05 according to Duncan's Multiple Range Test in SAS 9.0.**

Figure 9 shows the percent sample weight loss due to termite attack for all treatment groups. As expected, the solid pine control group fared the worst, with an average weight loss of 29.00 percent. The untreated strandboard group experienced 17.32 percent weight loss, and the treatments of 10 percent PD-112, 17 percent PD-112 and 23 percent PD-112 lost 6.10 percent, 7.13 percent and 4.54 percent of their oven dried weights, respectively. There were four significantly different groups by weight loss: group A consisting of the untreated pine controls, group B consisting of the untreated strandboard controls, group C consisting of the 10 percent PD-112 and 17 percent PD-112 groups, and group D consisting of the 10 percent PD-112 and 23 percent PD-112 groups.

Average sample visual rating for all treatments can be seen in Figure 10. These visual ratings are based on a scale of 0 to 10; 0 represents sample failure 10 represents no visual termite damage. Four significant groups emerged with respect to sample rating.

Group A consisted of the 23 percent PD-112 samples, group B consisted of the 17 percent PD-112 and 10 percent PD-112 groups,

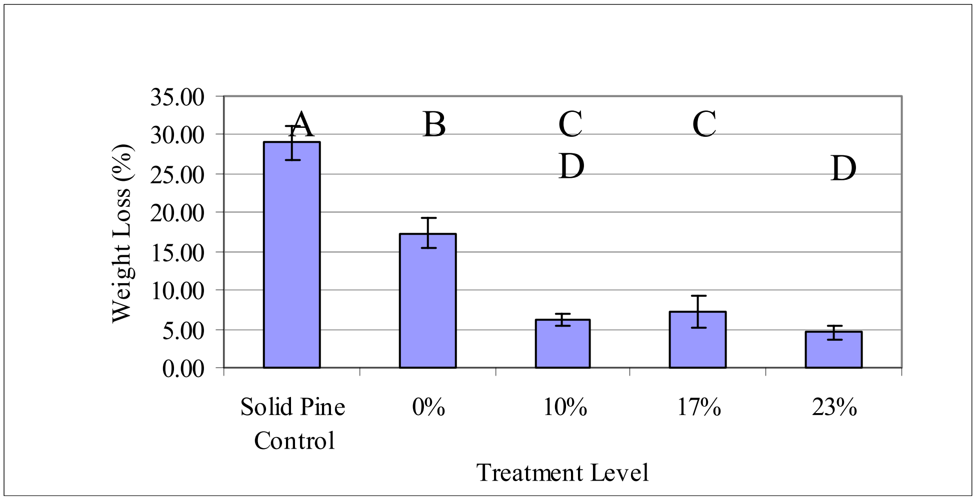


**Figure 9. Percent sample weight loss for all treatments after four weeks in no-choice termite jar test. Vertical error bars represent 95% confidence interval around mean. Means sharing capital letter do not differ at α = 0.05 according to Duncan's Multiple Range Test in SAS 9.0.**

group C consisted of the untreated strandboard samples and group D consisted of the untreated solid southern yellow pine samples. Groups A, B, C and D had average ratings of 8.60, 7.30, 3.87 and 0.33, respectively.

Within group B, 10 percent PD-112 and 17 percent PD-112 showed ratings of 7.00 and 7.60, respectively. As with termite mortality, the high sample weight loss and corresponding low visual rating for the solid pine group demonstrate a high degree of termite activity during testing, suggesting good termite health and vigor.

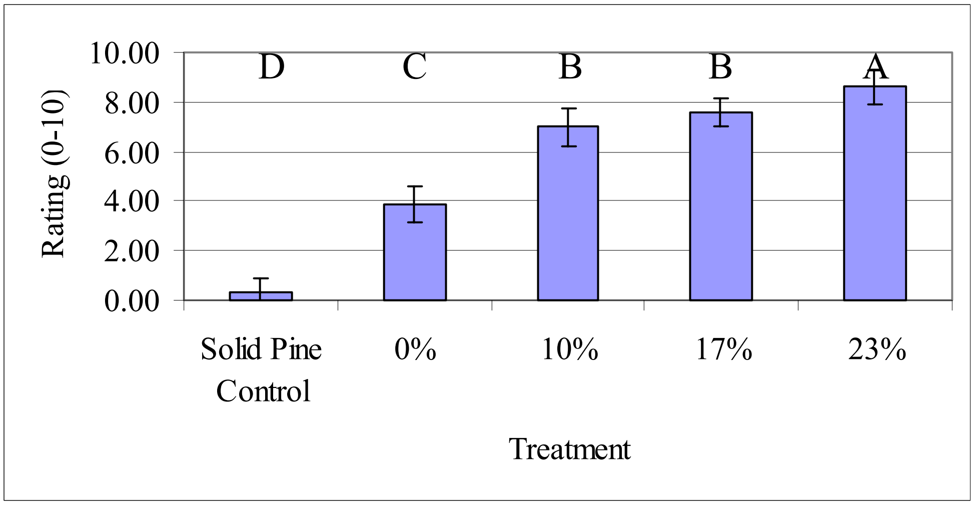


**Figure 10. Visual sample rating (scale of 0-10) for all treatments after four weeks in no-choice termite jar test. Vertical error bars represent 95% confidence interval around mean. Means sharing capital letter do not differ at α = 0.05 according to Duncan's Multiple Range Test in SAS 9.0.**

**Conclusions**

At all treatment levels, PD-112 imparted definite termite resistance compared to untreated (control) solid pine and pine strandboard. At the lowest treatment level (10 percent), rating increased from 0.33 (untreated solid pine) and 3.87 (untreated strandboard) to 7.00. At the highest level (23 percent), the average rating was 8.60. Sample weight loss for controls was 29.00 and 17.32 percent (solid pine and strandboard, respectively), while 10 percent, 17 percent and 23 percent PD-112 treatment experienced weight loss of 6.10 percent, 7.12 percent and 4.54 percent, respectively.

With respect to rating, 23 percent PD-112 gave slightly less protection than ZB at 1.78 percent BAE (rating = 8.86), and better protection than CB at 3.07 percent BAE (rating = 8.12). ZB at 1.04 percent BAE gave better protection against weight loss than 23 percent PD-112, whereas CB at 0.99 percent BAE to 3.07 percent BAE and 23 percent PD-112 protected pine strandboard approximately equally (Lee et al. 2004).

CCA, at retention levels from 1.6 $kg/m^3$ to 6.4 $kg/m^3$ provided better protection to solid pine wafers from weight loss than 23 percent PD-112 provided for strandboard. For CCA, ratings varied from 9.0 to 9.6, and weight loss was between 1.28 percent and 0.62 percent (Grace 1998).

# Chapter 5.

## Fungal Decay Resistance

### Materials and Methods

The Standard Test Method for Wood Preservatives by Laboratory Soil-Block Cultures (ASTM D 1413-76) was used to determine resistance of PD-112 treated OSB to decay by brown rot fungi. This test provides a determination of preservative's minimum effective treatment level for preventing decay of selected wood species by selected fungi under laboratory conditions, relative to an untreated control.

#### Test Setup

The soil block test consisted of an eight ounce French square culture bottle containing soil, water, and a softwood (*Pinus* spp.) feeder strip supporting a test specimen. The loam soil supplied by the Louisiana State University Macon Ridge Agricultural Experiment Station in Winnsboro, LA had a pH of 4.7 and moisture holding capacity of 24.31 percent. After passing through a number 10 sieve, 100 grams of soil was added to each jar, followed by 28.37 grams of distilled water (130 percent of moisture holding capacity). A feeder strip was then added to each jar, onto which a test specimen was placed. The completed jars were then sterilized in an autoclave to avoid mold contamination. Five samples from each treatment level and five untreated southern yellow pine specimens were used. This was repeated for both fungus species tested: *Poria placenta* and *Gloeophylum trabeum*. Test cultures were obtained from Dr. John Jones of the Louisiana State University Plant Pathology Department. Test specimens were 2.54 cm by 2.54 cm by 1.27 cm (one in by one in by 0.5 in in size). After sterilization, the soil in each jar was inoculated with the appropriate fungus.

Evaluation

After 12 weeks, the specimens were removed, oven dried and weighed to determine weight loss. Table 8 shows the scale used to classify samples according to decay resistance.

**Table 8. Resistance scale for evaluation of soil block samples. Samples were exposed to the decay fungi *Gloeophylum trabeum* and *Poria placenta* for 12 weeks.**

| % Average Weight Loss | Indicated Resistance Class |
|---|---|
| 0-10 | Highly Resistant |
| 11-24 | Resistant |
| 25-44 | Moderately Resistant |
| 45-100 | Slightly Resistant or Nonresistant |

**Results and Discussion**

Decay Resistance

Figure 11 shows the weight loss experienced by samples of all treatments following 12 weeks exposure to the decay fungi *Poria placenta* and *Gloeophylum trabeum*. These specific fungi, both brown rot basidiomycetes, are well suited to this test because of their preference for softwood species. *G. trabeum* is a particularly good choice for this test, described by ASTM (1999) as "a fungus particularly tolerant to phenolic and arsenic compounds." As also seen in the termite test, greatest weight loss was experienced by the untreated solid pine group, followed by the untreated OSB. The three IRL treatments exhibited much lower weight loss than the controls. For the untreated controls (both solid wood and OSB), *P. placenta* caused greater weight loss than did *G. trabeum*, but for the three IRL treated groups, the difference in weight loss between the two fungi species was negligible. In Figure 12, we see the sample

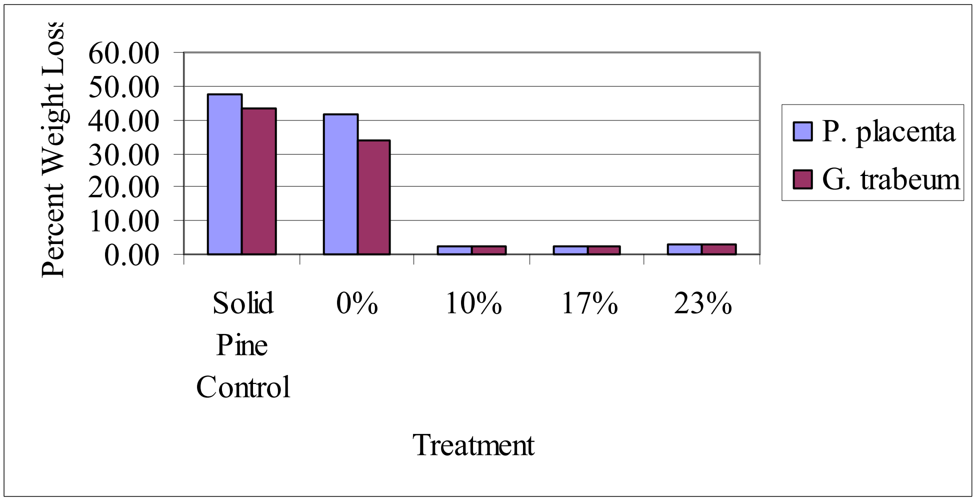


**Figure 11. Sample weight loss after 12 weeks exposure to the decay fungi *Gloeophylum trabeum* and *Poria placenta.***

percent weight loss after 12 weeks exposure to *Poria placenta* for all treatment groups. Three significantly different groups became evident. Group A consisting of the untreated solid pine controls experienced weight loss of 47.68 percent. Group B consisting of the untreated OSB controls experienced weight loss of 41.46 percent. Group C consisting of the 10 percent IRL group, 17 percent IRL group, and 23 percent IRL group (showing individual weight loss of 2.23 percent, 2.50 percent and 2.92 percent, respectively) experienced an average weight loss of 2.55 percent.

Figure 13 shows the sample percent weight loss after 12 weeks exposure to *Gloeophylum trabeum*. As with *P. placenta* testing, three significantly different groups became evident. Group A consisting of the untreated solid pine controls experienced weight loss of 43.08 percent. Group B consisting of the untreated OSB controls experienced weight loss of 33.75 percent. Group C consisting of the 10 percent IRL group, 17 percent IRL group, and 23 percent IRL group (showing individual weight

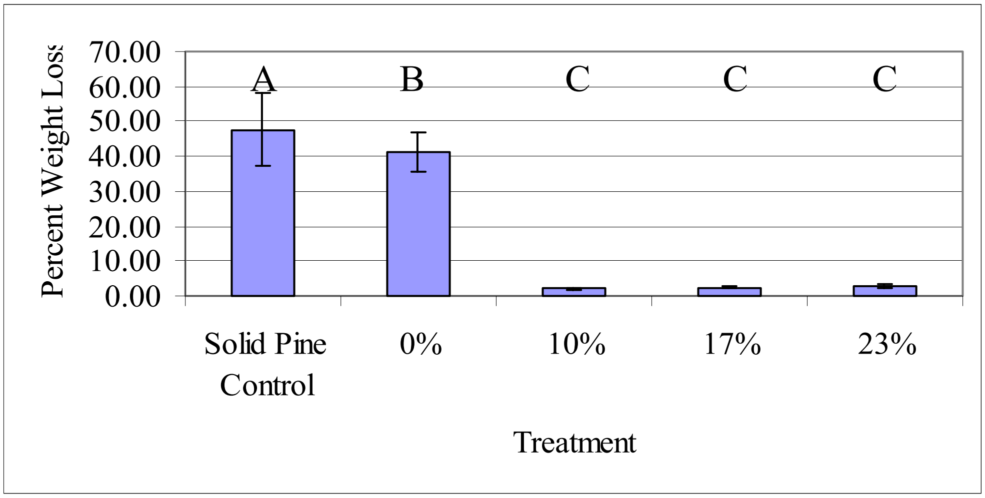


**Figure 12. Sample weight loss after 12 weeks exposure to the decay fungus *Poria placenta*. Means sharing a capital letter do not differ at the α= 0.05 level according to Duncan's Multiple Range Test in SAS 9.0.**

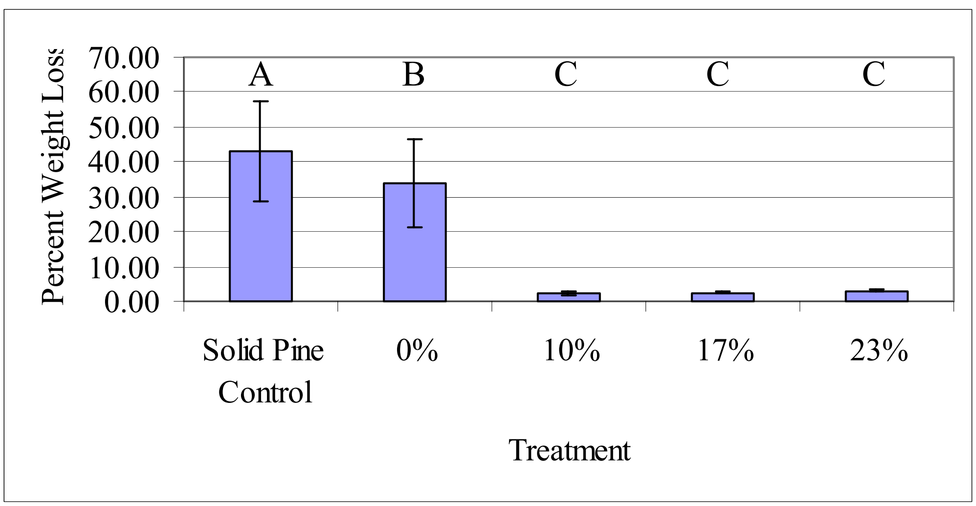


**Figure 13. Sample weight loss after 12 weeks exposure to the decay fungus *Gloeophylum trabeum*. Means sharing a capital letter do not differ at the α= 0.05 level according to Duncan's Multiple Range Test in SAS 9.0.**

loss of 2.29 percent, 2.58 percent and 3.13 percent, respectively) experienced an average weight loss of 2.66 percent.

**Conclusions**

At all treatment levels, PD-112 provided excellent protection to pine strandboard against decay by *P. placenta* and *G. trabeum*. Weight loss after 12 weeks exposure to the fungi for all IRL levels was 3.12 percent or less for both fungi species tested. Results from Jeihooni et al. (1994) showed weight loss of up to 1.93 percent for CCA-C and up to 3.70 for borate treated Douglas fir (compared to 50.3 percent for untreated samples) after *P. placenta* exposure. Sean et al. (1999) saw approximately 2 percent weight loss for borate treated Aspen OSB (compared to 40 percent for untreated samples) after *G. trabeum* exposure.

# Chapter 6.

## Mold Resistance

### Materials and Methods

Mold testing conducted was adapted from a draft of the AWPA Standard Test Method for Resistance to Growth of Mold on the Surface of Interior Coatings in an Environmental Chamber (ASTM EXX-XX). This test was used to evaluate the comparative resistance of PD-112 treated OSB panels to mold growth. An environmental chamber was constructed to allow exposure of test specimens to mold cultures at controlled temperature and humidity levels—95-98 percent relative humidity at 32.5 ± 1$^{o}$C. Six samples from each PD-112 treatment level and an untreated control were tested. Test specimens were 7.62 cm by 10.16 cm (three in by four in). A tray of greenhouse-grade potting soil was inoculated with a mixture of prescribed mold species. The species used were *Aureobasidium pullulans, Aspergillus niger, Penicillium citrinum,* and *Alternaria tenuissima.* After a two week incubation period, the specimens were lightly misted with a suspension of spores from the above listed species. The innoculum was prepared by rinsing spores from a fully colonized Petri dish with a mixture of distilled water and Tween 80.

Test specimens were suspended vertically within the chamber with the bottom of the panel 7.62 cm (three inches) above the inoculated soil. Duration of the test was eight weeks.

#### Evaluation

Every two weeks following introduction to the mold chamber, samples were visually evaluated to determine mold growth. The rating process was comprised of two components--growth intensity and coverage area. The intensity component evaluated the percentage of the sample surface that had mold growth so great as to obscure the sample's color. The coverage component simply quantified the percentage of the sample surface that exhibited visible mold growth. Table 9 summarizes the rating system. Each sample was given two independent ratings, one based on coverage and the other based on intensity.

**Table 9. Mold rating scale.**

| Rating | Coverage Percentage | Intensity Percentage |
|---|---|---|
| 0 | 0% | 0% |
| 1 | <10 % | <5% |
| 2 | 10 % -30 % | 5 % -10% |
| 3 | 30 % -70 % | 10 % -30 % |
| 4 | >70 % | 30 % -70 % |
| 5 | 100% | >70 % |

After rating, the more severe of the two values for each sample rating (area, intensity) was assigned to the sample.

**Results and Discussion**

Mold Resistance

Tables 10 and 11 show the rating values and corresponding surface protection percentage for all treatment groups at all measurement points during the test. Capital letters to the right of the rating values indicate significant differences in ratings among treatment groups within a specified exposure time (i.e. within a column). Lower case letters indicate significant differences in ratings among exposure times within a specified treatment group (i.e. within a row).

Ten percent PD-112 treatment did not offer any significant improvement over untreated Southern Yellow Pine regarding mold prevention, but as the treatment level increased to 17 percent PD-112, a slight improvement was noted. Twenty three percent PD-112 offered the best resistance to mold growth, but still fell short of the 100 percent protection levels achieved by Baileys' (2003) water-repellent preservatives and the 1.0 rating for 1.76 % BAE reported by Fogel and Lloyd (2002).

**Table 10. Mold rating summary.**

| Treatment | Exposure Time (Weeks) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 | | 4 | | 6 | | 8 | |
| Solid Pine Control | 3.00 (1.04) | A a | 4.42 (0.79) | B b | 4.92 (0.29) | A bc | 5.00 (0.00) | A c |
| OSB Control | 4.17 (0.58) | A a | 5.00 (0.00) | A b | 5.00 (0.00) | A b | 5.00 (0.00) | A b |
| 10% PD-112 | 3.75 (0.62) | A a | 4.75 (0.45) | AB b | 4.92 (0.29) | A b | 4.67 (0.49) | A b |
| 17% PD-112 | 3.42 (0.79) | B a | 3.75 (0.45) | C ab | 3.92 (0.92) | B a | 4.00 (0.00) | B a |
| 23% PD-112 | 2.50 (0.52) | C ab | 2.92 (0.67) | D ab | 1.92 (0.79) | C b | 2.33 (0.89) | C ab |

**Table 11. Surface protection summary.**

| Treatment | Exposure Time (Weeks) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 | | 4 | | 6 | | 8 | |
| Solid Pine Control | 71-90% | A a | 30-70% | B b | <30% | A bc | <30% | A c |
| OSB Control | 30-70% | A a | <30% | A b | <30% | A b | <30% | A b |
| 10% PD-112 | 30-70% | A a | <30% | AB b | <30% | A b | <30% | A b |
| 17% PD-112 | 71-90% | B a | 30-70% | C ab | 30-70% | B a | 30-70% | B a |
| 23% PD-112 | 71-90% | C ab | 71-90% | D ab | 91-95% | C b | 91-95% | C ab |

A summary of ratings for all treatment groups at two week intervals is displayed in Figure 14. A general trend emerges with respect to the manufactured test specimens, and is followed throughout the test. For all of the periodic ratings, the untreated control strand board received the highest rating (greatest amount of mold coverage), followed by the 10 percent, 17 percent and 23 percent PD-112 groups. The untreated solid pine specimens did not exhibit a great degree of visible mold growth during the early stages of the test, but by the eighth week, had caught up with the untreated strandboard control

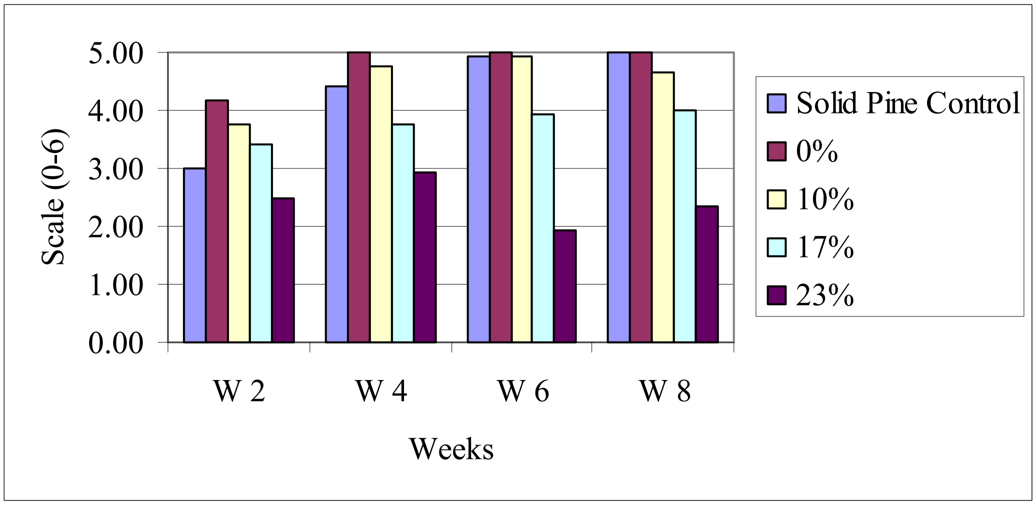


**Figure 14. Mold coverage for all groups, two week intervals.**

group to exhibit the maximum rating of five. A discrepancy appears with respect to the 23 percent PD-112 group between weeks four and eight. The 23 percent PD-112 group exhibits a decrease in rating between week four and week six (from 2.92 to 1.92), then a rebound between week six and week eight (from 1.92 to 2.33). The 10 percent PD-112 group appears to exhibit a similar phenomenon, but there is no significant difference between the rating values obtained during week six and week eight for the 10 percent PD-112 group.

**Figure 15. Samples after mold testing. Top row: untreated solid pine, untreated pine strandboard. Bottom row: 10 percent PD-112, 17 Percent PD-112 and 23 Percent PD-112**.

Figure 16 summarizes the final ratings for all treatment groups after eight weeks in the mold chamber. The untreated solid pine group and the untreated strand board group both exhibited the maximum rating of 5.00, and the 10 percent PD-112 group showed a rating of 4.67. There was no significant difference among these three groups a the α= 0.05 level. The 17 percent PD-112 and 23 percent PD-112 were significantly different, with ratings of 4.00 and 2.33, respectively.

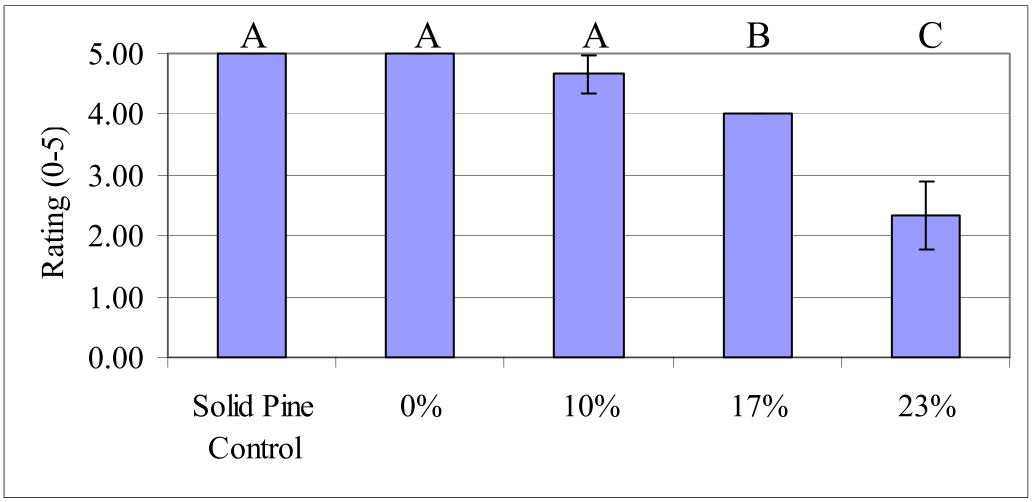


**Figure 16. Mold coverage, eight weeks exposure.**

**Conclusions**

PD-112 provided some resistance to mold growth, reducing coverage from a rating of 5 (100 percent coverage) after four weeks for untreated (control) pine strandboard to 2.92 (approximately 70 percent protection) for 23 percent PD-112 panels. Baileys et al. (2003) observed 100 percent surface protection after four weeks exposure with their water based preservatives (WB-1, WB-2 and WB-3), when applied as a dip; when applied in a rotary blender (i.e. lower retention levels), as PD-112 was applied, surface protection dropped to 83 percent for WB-1. Fogel and Lloyd (2002) observed only "traces of mold growth" after four weeks exposure with their borate treated aspen

OSB at 1.76 percent BAE, compared to “moderate” growth (30 percent to 60 percent coverage) on untreated boards.

# Chapter 7.

## Conclusion

Results from these tests indicate that PD-112 is effective at enhancing durability of composite pine products bonded with phenol formaldehyde resin. PD-112 produces no adverse effects on strength properties of pine products, and provides excellent resistance to thickness swelling and delamination due to moisture infiltration. PD-112 treated panels at 10 percent or greater IRL were very resistant to brown rot, but only moderately resistant to mold growth. Termite damage, although not completely eliminated, was greatly reduced by PD-112 incorporation.

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## Vita

Matthew Voitier was born in Opelousas, Louisiana on April 7, 1980. He graduated from Westminster Christian Academy in the spring of 1997 and went on to pursue his Bachelor of Science degree at Mississippi State University in Starkville, Mississippi in the fall of 1997. His interest in the outdoors led him to study forestry while at Mississippi State University, and he earned his Bachelor of Science degree in Forest Management in the spring of 2001. After taking a semester off to work in the transportation industry, Matthew returned to school to pursue his Master of Science degree in Forestry at Louisiana State University in Baton Rouge, Louisiana under the direction of Dr. W. Ramsay Smith in the spring of 2002. Master of Science degree in Forestry will be awarded in December, 2004.