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Technical feasibility of flakeboard production from recycled CCA-treated wood

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TECHNICAL FEASIBILITY OF FLAKEBOARD PRODUCTION FROM RECYCLED CCA-TREATED WOOD

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ABSTRACT

Chromated copper arsenate (CCA) treated wood is an economical, durable and aesthetically pleasing residential material used for many exterior application such as decks, fences, playground equipment, utility poles, and others. It has been most widely used in North America since the 1970's. A large volume of CCA-treated wood is currently coming out of service. Traditional landfilling or incineration is environmentally unacceptable. Recycling CCA-treated wood into composite products is one alternative to ease the disposal problem. It also has the potential to relieve harvesting pressure from the nation's forestlands. After recycling, the remaining CCA content in the wood can still have preserving capability against decay. In this study, the effects of different ratios of recycled CCA-treated wood and untreated virgin wood on flakeboard properties were compared. The mechanical, physical, decay resistance, elemental concentrations, and leaching characteristics of flakeboards manufactured from five different ratios of recycled CCA-treated wood and untreated virgin southern pine wood were investigated. The ratios were 100:0, 75:25, 50:50, 25:75, and 0:100. The CCA retention levels of out-of-service CCA-treated posts (experimental raw material) as well as the flakeboard fabricated from the different ratios of recycled CCA-treated wood and untreated virgin wood were also tested. The median ratio with 50% of CCA-treated wood and un-treated wood was found to be the optimum combination. In this case, residual CCA level was sufficient enough to prevent substantial weight losses for the

decay tests but low enough so that panel mechanical and physical properties were not substantially adversely affected.

CHAPTER 1. INTRODUCTION

1.1. Introduction

Preservative-treated wood is economical, durable, and aesthetically pleasing. Waterborne preservatives, pentachlorophenol (penta) and creosote are the three predominant wood preservatives presently used in North America. Figure 1 shows the volumes of wood treated with different preservatives in the United States from 1960 to 1998 (Cooper 1994, Micklewright 1998). Approximately six million m^3 of wood treated with CCA, pentachlorophenol and creosote are disposed of annually and about nineteen million cubic meters per year will be available for recycling by 2020 (Felton and De Groot 1996). Figure 2 displays the trend of future volumes of treated wood removed from service in the United States (Cooper 1994).

CCA is a waterborne inorganic preservative that contains copper, chromium and arsenic. There are three types of CCA preservatives depending upon the relative proportions of metals with type C being the most common (Table 1). CCA-treated wood is most widely used to treat exterior lumber in North America for many uses including decks, gazebos, playground equipment, landscape timbers, and agricultural stakes, marinas and utility poles. The amount of CCA utilized to treat the wood and retention levels depend upon the particular application for the wood product (Table 2). For the past two decades, CCA has emerged as the primary wood preservative for residential and commercial applications (Smith and Shiau 1998). Over 6 billion board feet (14.2 million cubic meters) of lumber

treated with CCA are produced annually in the United States (Micklewright 1998). If the preservative is applied properly, the physical service life should be extended by 20 to 50 years or more depending on the method of treatment and conditions of service (Cooper 1993b). When a treated wood product reaches the end of its service life, either through mechanical damage or failure, biological deterioration, or obsolescence, these products may be salvaged, abandoned in place, or removed from active service for disposal. Cooper (1993c) estimated that the future volumes of CCA-treated wood removed from service in the United States would rise from 1 million m^3 in 1990 to 16 million m^3 in 2020.

The increasing volume of CCA treated wood products coming out of service is posing disposal problems. Typical waste disposal options such as landfilling or incineration are both environmentally unacceptable and expensive. Moreover, there is increasing public concern and restrictions on disposal due to potential adverse effects on human health and the environment. Many scientists have studied various options to resolve these problems, including reuse, abatement, modification, recycling, retreatment, and destruction (Cooper 1993b and 1996). The recycling option is potentially economically feasible and definitely environmentally attractive. The potential for recycling preservative-treated wood is great, while recycling into wood composite products can be regarded as the most viable option (Cooper 1999, Felton and De Groot 1996). Moreover, the significant quantities of residual CCA content in the wood can still have preserving capability against decay (Cooper 1996, Cooper *et al.* 1996). Therefore, CCA-treated wood

could be a high-quality resource to produce sheathing or flooring for decay-risk applications (Munson and Kamdem 1998).

Table 1: Composition of CCA-type A, B, and C (AWPA 2000).

	CCA-Type A	CCA-Type B	CCA-Type C
Chromium as CrO_3	65.5%	35.3%	47.5%
Copper as CuO	18.1%	19.6%	18.5%
Arsenic as As_2O_5	16.4%	45.1%	34.0%

Table 2: Retention requirements for CCA-treated wood (AWPA 2000).

Applications	Retention Value (pcf)
Above ground: lumber, timbers, and plywood	0.25
Ground/Freshwater contact: lumber, timbers, plywood	0.40
Salt water splash, wood foundations: lumber, timbers, and plywood	0.60
structural poles	
Foundation/Freshwater: pilings and columns	0.80
Salt water immersion: pilings and columns	2.50

Oriented strand board (OSB) plays a major role in structural siding, sheathing and flooring of residential construction and other applications. Over the last two decades, OSB has experienced tremendous growth in the structural wood-based panel market. Economic forecasts project a continuing domination of

the wood sheathing market by OSB (Zhu *et al.* 1998). Imparting decay and/or insect resistance to OSB could broaden its application in terms of new uses, particularly for exterior use in areas classified as high decay risk zones such as Louisiana. Therefore, OSB made from out-of-service treated wood could provide substantial benefits for many user groups. The wood-preserving industry would benefit from such a product because the service life of the treated wood could be extended, thus alleviating pressure to find ways to dispose of their products. OSB producers would gain a new furnish that would reduce the cost of harvesting trees and the environmental stresses of over-harvesting.

Flakeboard, in which the flake orientation is random, simplifies the procedure of panel assembling and eases to manufactory in laboratory. The orientation of flakes will definitely increase panel properties. Various studies on particleboard (PB), flakeboard and cement-wood particleboard using CCA-treated wood furnishes have been conducted. However there is very little data about the feasibility and properties of flakeboard from recycled CCA-treated, southern pine (*Pinus sp.*) wood in the literature. A systematic study on the properties of flakeboards will provide useful information for commercial panel production and utilization.

1.2. Objectives

The primary objective of this study was to determine the technical feasibility of flakeboard production from recycled CCA-treated southern pine (*Pinus sp.*) wood. The effects of different ratios of recycled treated wood and untreated virgin

wood on flakeboard panel properties were investigated. The study consisted of three specific objectives.

1. Determine the effect of the ratio of recycled CCA-treated wood and untreated virgin wood on flakeboard panel properties, including modulus of elasticity (MOE), modulus of rupture (MOR), internal bond (IB), thickness swell (TS), linear expansion (LE), water absorption (WA), and decay resistance.

2. Determine copper, chromium, and arsenic retention levels of out-of-service CCA-treated highway guardrails and flakeboard panels fabricated from different ratios of recycled CCA-treated wood and untreated virgin wood.

3. Evaluate the leaching performance of flakeboard panels made from five different ratios of recycled CCA-treated wood and untreated virgin wood.

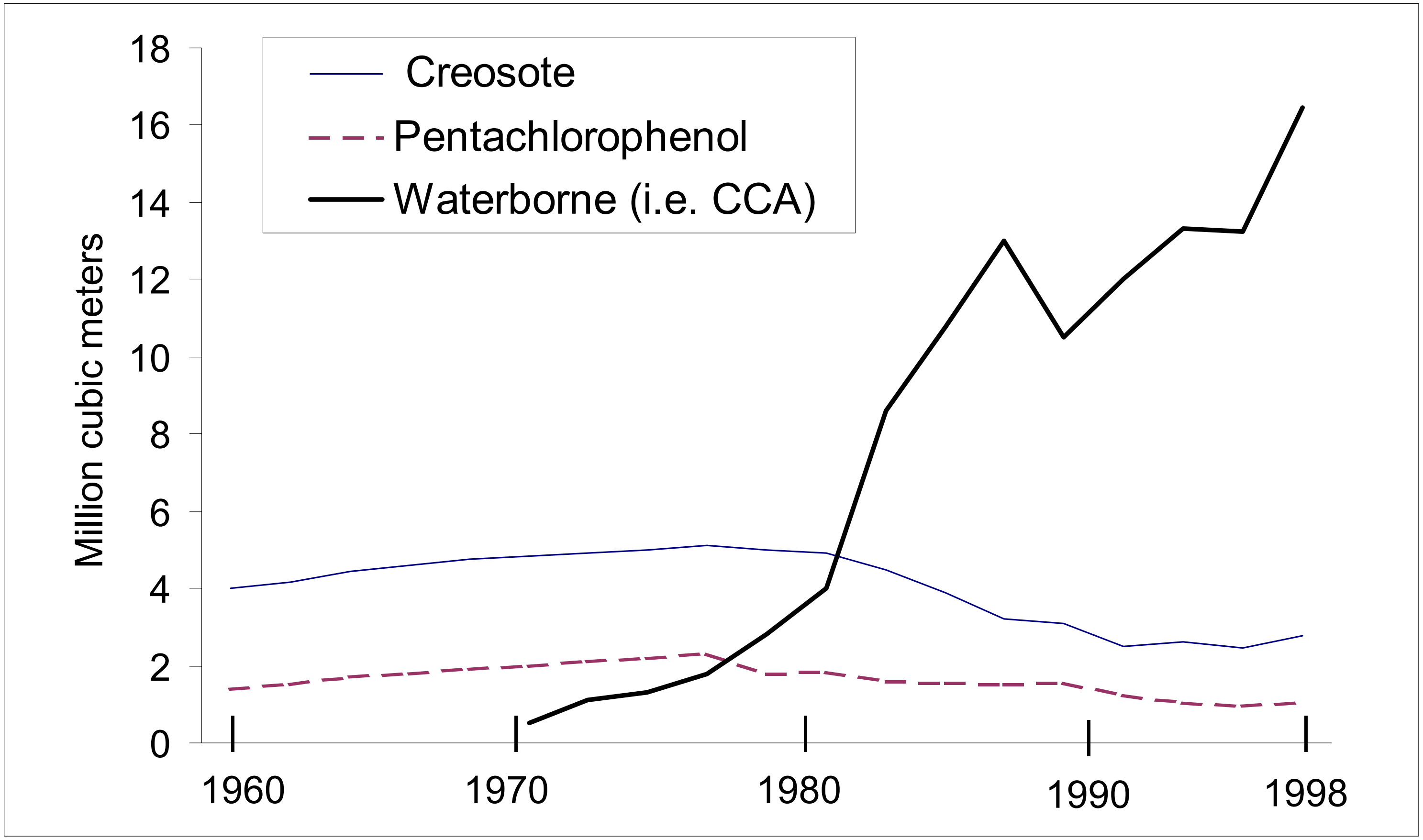


Figure 1. Volumes of wood treated by different preservatives in the United States.

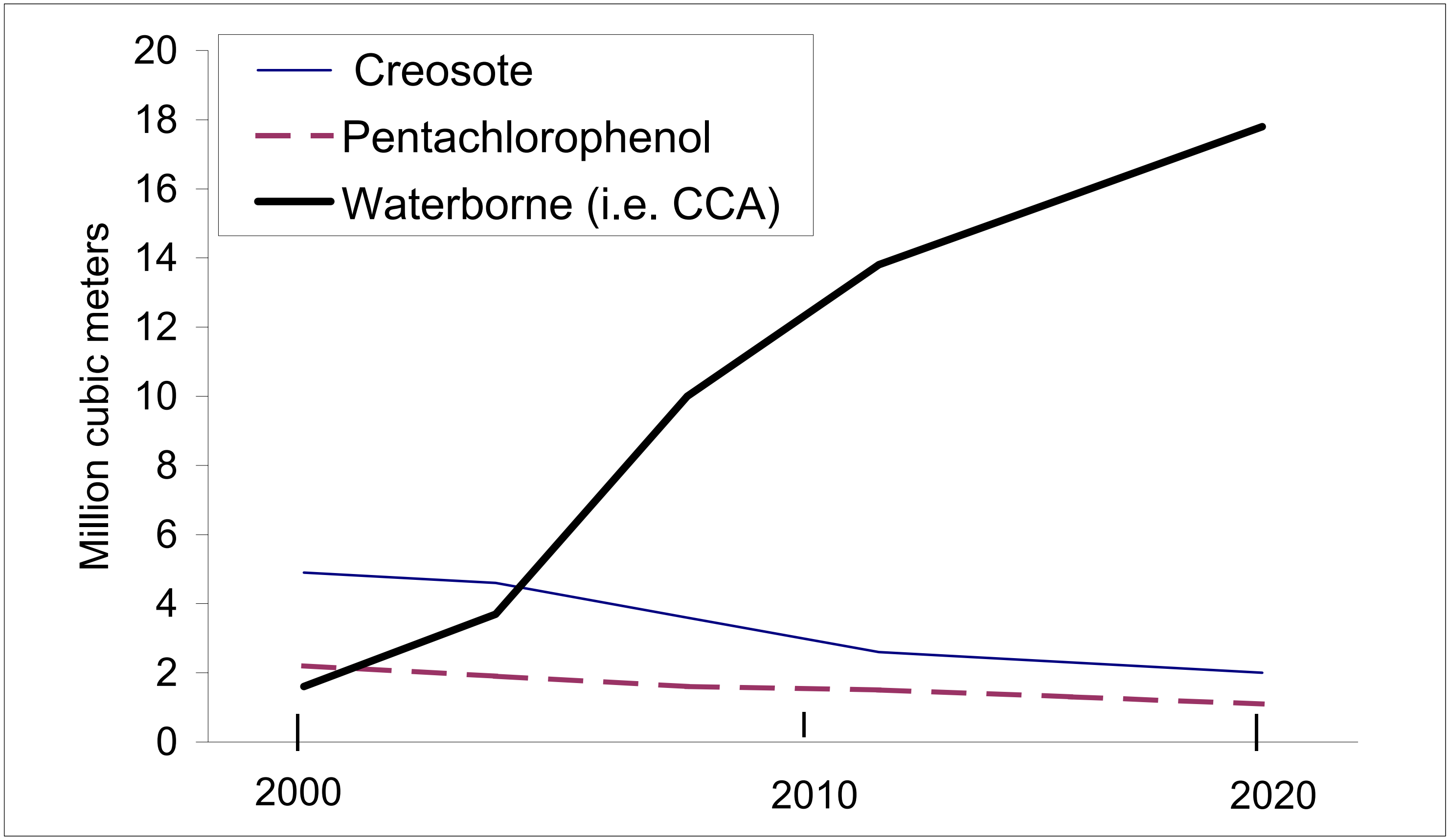


Figure 2. Estimates of future volumes of treated wood removed from service in the United States.

CHAPTER 2. LITERATURE REVIEW

2.1. Physical and Mechanical Properties

It is generally known that CCA-treated wood is more difficult to properly bond in many applications than untreated wood. Early research by Choong and Attarzedah (1970), and Hutchinson *et al.* (1977) on the properties of phenol-formaldehyde (PF) bonded plywood made from veneer treated with CCA showed that the percent wood failure and shear strength of treated plywood were less than that of untreated plywood. Many scientists have continued to search for causes and solutions for this issue. The limited success of bonding CCA-treated wood is attributable to preservative interference with adhesion to the treated wood (Vick and Kuster 1992, Vick and Christiansen 1993).

Many of the same problems encountered with gluing CCA-treated veneer have also been found with particle-based composites (Boggio and Gertjejansen 1982, Clausen *et al.* 2001, Felton and De Groot 1998, Hall *et al.* 1982, Jeihooni *et al.* 1994, Lebow and Gjovik 2000, Munson and Kamdem 1998, Vick *et al.* 1996). In general, these studies have reported lower mechanical and physical property values from composite boards fabricated from recycled CCA-treated wood than those from untreated particles. Therefore, scientists have studied the feasibility of several possible solutions to increase bonding properties. As expected, increasing the resin content increased the properties of the board (Boggio and Gertjejansen 1982, Munson and Kamdem 1998, Vick *et al.* 1996). Vick *et al.* (1996) found that a hydroxymethylated resorcinol-coupling agent could enhance physical and

mechanical properties, particularly IB strength, of the CCA-treated flakeboards (Vick 1997). Schmidt *et al.* (1994), Huang and Cooper (2000) stated that CCA-treated wood produced stronger wood-cement composites compared to untreated wood. Clausen *et al.* (2001) pressed remediated CCA-treated wood particles using a two-step method into particleboard, but lower strength board properties were reported.

Munson and Kamdem (1998) showed the feasibility of producing particleboard with mixed CCA-treated and untreated uniform red pine (*Pinus resinosa*) particles. Their study revealed that an ideal ratio of CCA-treated and untreated particles might maximize the board properties.

2.2. Decay Resistance

Generally, particleboard is considered more decay resistant than solid wood, from which the particleboard is made, but the rate of deterioration is affected by many factors (Behr 1972, Merrill *et al.* 1965). Toole and Barnes (1974) summarized that wood species, type of adhesive, particle size and geometry and physical properties of the panel are major variables for panel decay resistance. Moisture content is also considered another important factor for decay. In particular, decay may not occur in a panel at zero percent moisture content (Toole 1969, Schmidt *et al.* 1978). Jeihooni (1994) stated that flakeboard treated with CCA preservative showed good resistance to brow rot fungus. Clausen *et al.* (2001) compared particleboard with recycled CCA treated particles and CCA-remediated particles. Their results showed that the more CCA removed from particles, the more weight loss during the decay test.

2.3. CCA Retention and Leaching

CCA is composed of the oxides or salts of chromium, copper, and arsenic. The copper in the wood serves as the fungicide whereas the arsenic protects the wood against insects. The chromium fixes the copper and arsenic to the wood. Theoretically, once CCA-treated wood is dry, the CCA is leach resistant under normal conditions (Hartfor 1986). CCA resists leaching during service because of complex chemical reactions that take place within the treated wood. The effectiveness of these reactions in preventing leaching is dependent on treating factors, such as preservative formulation, preservative retention, and processing techniques, as well as post-treatment conditioning factors, such as temperature, humidity, and airflow (Lebow 1996). Munsen and Kamdem (1998) found the retention of CCA in particleboard fabricated from CCA-treated wood was higher than that of treated wood. Also, their experiment showed no chromium and copper ions leaching but some arsenic ions were found in the laboratory test.

CHAPTER 3. MATERIALS AND METHODS

3.1. Materials

- Guardrail Posts:

Twenty-five highway guardrail posts manufactured from southern pine (*Pinus sp.*), were obtained from Arnold Forest Products Company in Shreveport, Louisiana. The posts, which had been treated with CCA, went in service in May, 1986 in Abilene, Texas and were removed in September 1999. These posts were about 69 inches (175.3 cm) long with a top diameter range of 6 ½ - 7 ½ inches (16.5 – 19.0 cm), and a bottom diameter range of 7 to 8 ¾ inches (17.8 – 22.2 cm). They were treated to 0.5 pcf and had been placed 38 inches into ground. After passing under an electronic metal detector, foreign metal objects were removed manually and the posts were transported to Lee Memorial Forest in Franklinton, Louisiana for processing into lumber. Twenty-two posts were sawn into 1-in. (2.5 cm) thick lumber using a WoodMizer® sawmill. The other three posts were retained for other tests, from which three disks, each 1-in. (2.5 cm) thickness, were cut from top, middle, and bottom and used for later chemical analyses.

- Flakes

Randomly selected boards were cut into blocks 3-in. (7.6 cm) wide and 1-in. (2.5 cm) thick. The blocks were submerged in tap water for 24 hrs. and flaked with a laboratory ring-flaker, which produced flakes about 3 x 1 x 0.05 in. (7.6 x 2.5 x 0.1 cm) in length, width, and thickness, respectively. Virgin flakes were produced

with the same procedures from fresh southern pine lumber, which was purchased at a local retail lumber store.

All flakes were dried to 4% moisture content at 217 ± 4°F (102 ± 2°C) for 3 hrs. and screened to remove fines (material passing through a screen with 1/4 $in.^2$ (1.6 cm^2) openings). Flakes then were conditioned at ambient conditions for 2 hrs. to reduce their temperature immediately prior to hot pressing.

- Adhesive

A liquid premixed phenol formaldehyde (PF) resin was obtained from Borden Adhesive Corporation. The resin had a solids content of 52%, viscosity of 400 cps, and a pH of 11.78. A 4.5% adhesive based on ovendry weight of flakes was used to bond all panels. The resin was removed from a refrigerator and warmed to 70°F (21°C) before blending with wood furnishes.

- Panel Fabrication

The flakes were blended with liquid PF resin in a laboratory rotary drum blender for 15 minutes. Flake mats were hand-formed in a frame (16.5 x 20 in. / 41.9 x 50.8 cm). Mats were hot pressed for 4 minutes until stops at 62 psi. with a platen temperature of 370°F (187.8°C). Flake orientation was random. Panels were conditioned for 1 week at ambient conditions prior to testing. Flakeboards were trimmed to 14 x 18 in. (35.6 x 45.7 cm) and cut into specimens for testing according to American Society for Testing Materials (ASTM) standard D 1037-93 (1998), APA - The Engineered Wood Association (1997), and American Wood-Preservers' Association (2000), respectively.

3.2. Experimental Design

Recycled CCA-treated flakes and untreated flakes were mixed at five ratios by weight: 100, 75, 50, 25, 0 percent treated wood content. Each of the five treatments combinations was replicated twice (Table 3).

Table 3. Experiment design.

Treatment	Ratio of CCA flakes vs. untreated flakes in percent
Group 1	100 : 0
Group 2	75 : 25
Group 3	50 : 50
Group 4	25 : 75
Group 5	0 : 100

3.3. Testing Methods

All tests were conducted under the standards of ASTM, APA-The Engineered Wood Association, and American Wood-Preservers' Association (AWPA) for evaluating the properties of flakeboards, respectively. Some minor modification was specified as follows.

- <u>Physical and Mechanical Properties</u>

Static bending tests were performed to determine MOE and MOR. Four samples that measured 2 × 14 in. (5.0 × 35.6 cm) were tested for MOR and MOE for each group. Twenty-four samples (2 × 2 in. (5.0 × 5.0 cm)) were tested for IB for each group.

The MOR, MOE, and IB tests were also performed after an oven dry vacuum-pressure-soak (ODVPS) treatment. The ODVPS IB and MOR, MOE tests contained 8 and 4 samples per group, respectively.

The ODVPS procedure was used for thickness swell, linear expansion and water absorption tests in accordance with APA test method P-1 (APA 1997). Four specimens (2 × 14 in. (5.0 × 35.6 cm)) from each group were tested. The ODVPS procedure requires specimens to be oven dried at 217 ± 4°F (102 ± 2°C) for 24 hours. Then, specimens are allowed to cool to room temperature, before vacuum-pressure soaking into tap water for one hour at 65 ± 10°F (18 ± 5°C) and a vacuum of 27 ± 2 in. (68.9 × 5.0 cm) of mercury.

The thickness swell, linear expansion and water absorption were calculated as a percentage of the original oven-dry dimension, as given in the equation below:

$$\text{Percent change (\%)} = \frac{L_w - L_d}{L_d} \times 100 \qquad [1]$$

Where, L_w = dimension saturated.

L_d = dimension Oven dried.

- Decay Resistance

The soil-block method is a widely adopted standard test for decay resistance of particleboard, flakeboard, and waferboard (Clausen *et al.* 2001, Jeihooni *et al.* 1994, Schmidt 1987, Schmidt *et al.* 1983, Toole and Barnes 1974). In accordance with AWPA Standard E10-91 (AWPA 2000), the soil block procedure for decay was done with a sandy loam soil with a water-holding capacity between 20% and 40% and a pH between 5.0 and 8.0. The panel samples were sawn into blocks measuring 1/2-in.^{3} (2.7 mm^3). Ten replications for each group were subjected to decay with the brown-rot fungus *Gloeophyllum trabeum* (ATCC isolate 11539) for 8 weeks, and the white-rot fungus *Trametes versicolor* (ATCC isolate 42462) for 16 weeks, respectively. For comparison purposes, 10 blocks of untreated southern pine sapwood (control) and CCA-treated guardrail posts sapwood were also subjected to each fungus. The guardrail posts that were tested were the same raw material used for flakeboard fabrication.

Weight loss was used to measure panel decay resistance, the formula is given as follows:

$$\text{Weight loss (\%)} = \frac{T_0 - T_1}{T_0} \times 100 \qquad [2]$$

Where, T_0 = initial test block weight.

T_1 = oven dry weight after subjected to fungi.

- Leaching Test

Leaching tests were done according to modified procedures of AWPA (2000) standard E11-97. Three test blocks with dimensions of 1/2-in.^{3} (2.7 mm^3) from each panel group were tested for leachability. The samples were submerged into 50 ml of deionized water. Three replications were performed. The water was replaced with an equal amount after 1 day, 7 days, 14 days, 21 days, and 28 days. Water samples were collected after each water replacement, and then were allocated into three equal parts of 15 ml each and analyzed for chromium, copper, and arsenic by inductively coupled plasma spectrometry – optimal emission spectrometry (ICP - OES).

- CCA Retention

The CCA retention test was conducted with 10 samples from each experimental panel group (Group 1-5). The samples measured 1/2-in.^{3} (2.7 mm^3). Also, three guardrail posts were selected and disks were removed at three vertical locations (top, middle, and bottom) from each guardrail (see 3.1 Materials – guardrail posts). From each disk, samples were removed at three horizontal locations (outer, middle, and inner). Therefore, a total of 9 samples per guardrail were tested for CCA retention, according to AWPA A-21-00, using ICP - OES.

3.4. Statistical Analyses

There was a single independent variable – percent of CCA-treated wood, where Group 1 – 5 were used to represent flakeboards contained five different ratios of CCA-treated wood and untreated virgin southern pine (Table 3). Two

panels that were manufactured by same ratio of CCA-treated wood and untreated wood content were considered as replicates to each treatment. Therefore, this design takes into account the nesting effect – the panels were nested in treatment groups (Marx 2001). The model was established to be the following:

$$Y_{ijk} = \mu + G_i + P(G)_{j(l)} + \varepsilon_{k(ij)} \quad [3]$$

Where,

μ = Overall mean.
G_i = Group (treatment) effect.
$P(G)_{j(l)}$ = Replication (panel) effect.
$\varepsilon_{k(ij)}$ = Experimental error.

Statistical Analysis System (SAS 2000) was used to statistically analyze the data of the mechanical, physical and decay resistance tests. The dependent variables in this study were: MOR, MOE, MOR-ODVPS, MOE-ODPVS, IB, IB-ODVPS, TS, LE, WA, decay resistance – brown rot and white rot. Data were subjected to analysis of variance (ANOVA) (Mendenhall et. al. 1999). The DUNNETT test and regression analyses were used to test variable relationships if the ANOVA was significant (Ramsey and Schafer, 2002). Statistical significance of difference between the groups was analyzed at α = 0.05 level.

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Mechanical and Physical Properties

The mechanical and physical properties of flakeboards are summarized in Table 4 and Table 5, respectively.

- <u>Bending strength</u>

The data in Table 4 indicate that the boards with 100 percent untreated flakes had highest MOR and MOE values. Also, mean MOR and MOE values decrease as the CCA-treated flake proportion increases (Figure 3 and Figure 4). This result agrees with previous finding (Boggio and Gertjejansen 1982, Clausen et al. 2001, Felton and De Groot 1998, Hall et al. 1982, Jeihooni et al. 1994, Lebow and Gjovik 2000, Munson and Kamdem 1998, Vick et al. 1996). Malony (1986) stated that flake geometry exerts the dominant control over bending strength. The relatively undamaged, long, flat flakes afforded boards higher bending strength. During the flakeboard manufacturing, it was visually observed that untreated virgin flakes have rectangular flat shape and uniformed size. However, the flakes from recycled CCA-treated guard rails generated more fine particles. According to the rule of mixture, the panels containing a higher percent of CCA-treated flakes, the lower the bending strength was obtained. Therefore, the bending strength value increased as the percent of CCA-treated flakes decreased from Group 1 to Group 5.

There are a couple of reasons to explain why flakes produced from guard rails contained more fines. Firstly, the guard rails were mainly produced by

plantation small diameter trees, which have higher percent of juvenile wood content. Juvenile wood is known to be less desirable for most processing operations, because of its lower density, physical and mechanical properties. Secondly, the experimental materials, guard rails, have been in service in outside conditions for 13 years. The quality of the wood was degraded due to weathering. Lastly, the wood was not sufficiently softened in order to produce high quality flakes.

The statistical analyses showed that the group effect (percent of CCA-treated wood content) resulted in no significant difference in the analysis of variance (Table 6). For each group comparison, there was no significance found (Figure 3 and Figure 4).

- Internal bond

The IB results are presented in Table 4 and Figure 5. Surprisingly, the IB strength with 100 percent CCA-treated flakes (Group 1) only had 5% reduction compared to those with 100 percent virgin flakes (Group 5). However, Group 2 contained 75% CCA-treated wood content had the lowest internal bond strength. Statistically, the difference among each group is significant (Table 6). These results differ from previous studies, which revealed similar trends for IB and bending strength (Boggio and Gertjejansen 1982, Clausen et al. 2001, Felton and De Groot 1998, Hall et al. 1982, Jeihooni et al. 1994, Lebow and Gjovik 2000, Munson and Kamdem 1998, Vick et al. 1996).

Theoretically, the internal bond of composite panel is mainly affected by resin content and spraying. Previous studies have also found that CCA

interferes with the bonding properties of wood and adhesive. It is known that CCA-treated wood is incompatible with phenol-formaldehyde adhesives (Boggio and Gertjejansen 1982, Prasan et al. 1994, Vick and Christiansen 1993, Vick et al. 1990), and CCA-treated wood has limited available lumen space, which adversely affects bonding on fiber surfaces (Felton and De Groot 1998, Vick and Kuster 1992). On the other hand, the density and density distribution is another important effect factor, on many panel properties.

- Bending strength after ODVPS treatment

After the ODVPS procedure, MOR values lowered from 27 – 47%, MOE value lowered from 34 – 51% (Figures 6 - 10). There was no significant difference (Table 6) of MOR and MOE after ODVPS treatment, while visually obvious increasing trends were observed from bar graphs from Group 1 to Group 5 (Figures 6 and 7).

- Internal bond after ODVPS treatment

IB strength of ODVPS specimens showed a similar result as the standard IB strength, in which the 100 percent virgin flakeboard and 100 percent CCA-treat flakeboard had slight variance, while the middle groups had the lower values (Figure 11 - 13). The reductions of each group are varied from 38 – 54% in terms of IB strength after ODVPS treatment. Analysis of variance showed that there is significance for treatment, in terms of different ratios (Table 6).

- Thickness swell, linear expansion, and water absorption

The data of thickness swell, linear expansion, and water absorption were listed in Table 4 and presented in Figures 14 –16. The significance in thickness

Table 4. Mechanical properties of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Treatment	MOR			MOE			IB		
	Standard	After ODVPS	Reduction by ODVPS	Standard	After ODVPS	Reduction by ODVPS	Standard	After ODVPS	Reduction by ODVPS
	(psi)	(psi)	(%)	(1000 psi)	(1000 psi)	(%)	(psi)	(psi)	(%)
Group 1	4,441	2,775	38	673	330	51	84.8	48.6	43
Group 2	4,894	2,609	47	694	406	42	65.1	35.0	46
Group 3	5,137	3,525	31	721	477	34	74.4	44.4	40
Group 4	4,743	3,468	27	700	462	34	72.2	33.0	54
Group 5	5,803	4,098	29	773	469	39	89.3	55.6	38

Table 5. Physical properties of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Treatment	Thickness (in.)	SG[a]	MC[b] (%)	Linear Expansion (%)	Thickness Swell (%)	Water Absorption (%)
Group 1	0.47	0.76	7.8	0.32	26.2	103
Group 2	0.47	0.76	7.6	0.31	28.4	100
Group 3	0.48	0.76	7.6	0.20	31.3	94
Group 4	0.48	0.76	7.3	0.26	33.2	98
Group 5	0.48	0.79	7.1	0.27	32.0	99

a: SG= specific gravity, oven dry based weight and air dry based volume.
b: MC = moisture content.

Table 6. Analyses of variance of mechanical and physical properties of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Sources	DF	Type III SS	TYPE III MS	F VALUE	PR > F
MOR	4	4208768	1052192	1.06	0.4254
MOE	4	2335317	583829	1.59	0.2518
MOR-ODVPS	4	5873253	1468313	1.27	0.3454
MOE-ODVPS	4	6127767	1531942	0.60	0.6739
IB[a]	4	9195	2299	8.94	<0.0001**
IB-ODVPS	4	5446	1361	9.47	<0.0001**
TS[b]	4	0.0130	0.0033	4.46	0.0252*
LE[c]	4	3.733E-6	9.335E-7	1.05	0.4272
WA[d]	4	0.0150	0.0038	1.10	0.4091
Brown rot	6	11691	1949	74.46	<0.0001**
White rot	6	238	40	19.78	<0.0001**

[a] Internal bond.
[b] Thickness swell.
[c] Linear expansion.
[d] Water absorption.
* Denotes significance at < 0.05.
** Denotes highly significance at < 0.01.

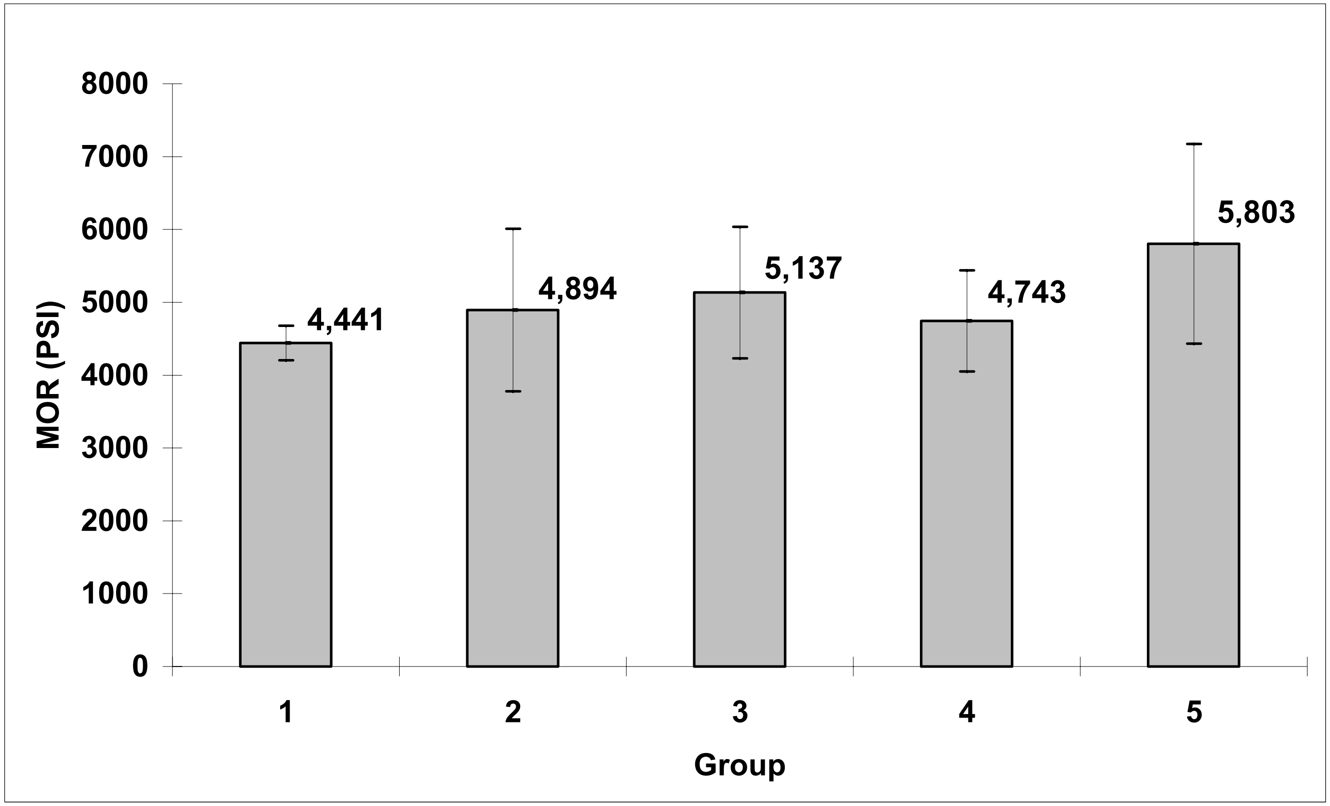


Figure 3. MOR tests of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

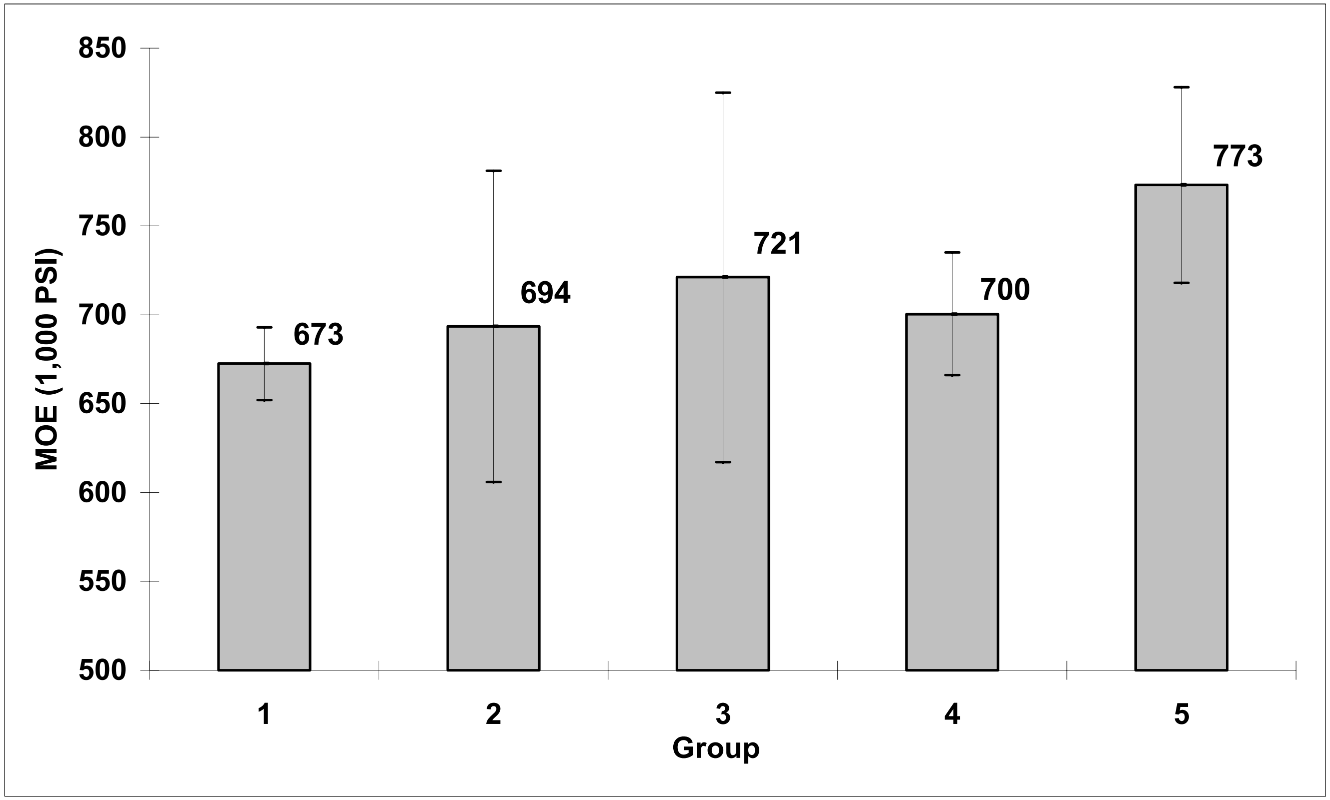


Figure 4. MOE tests of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

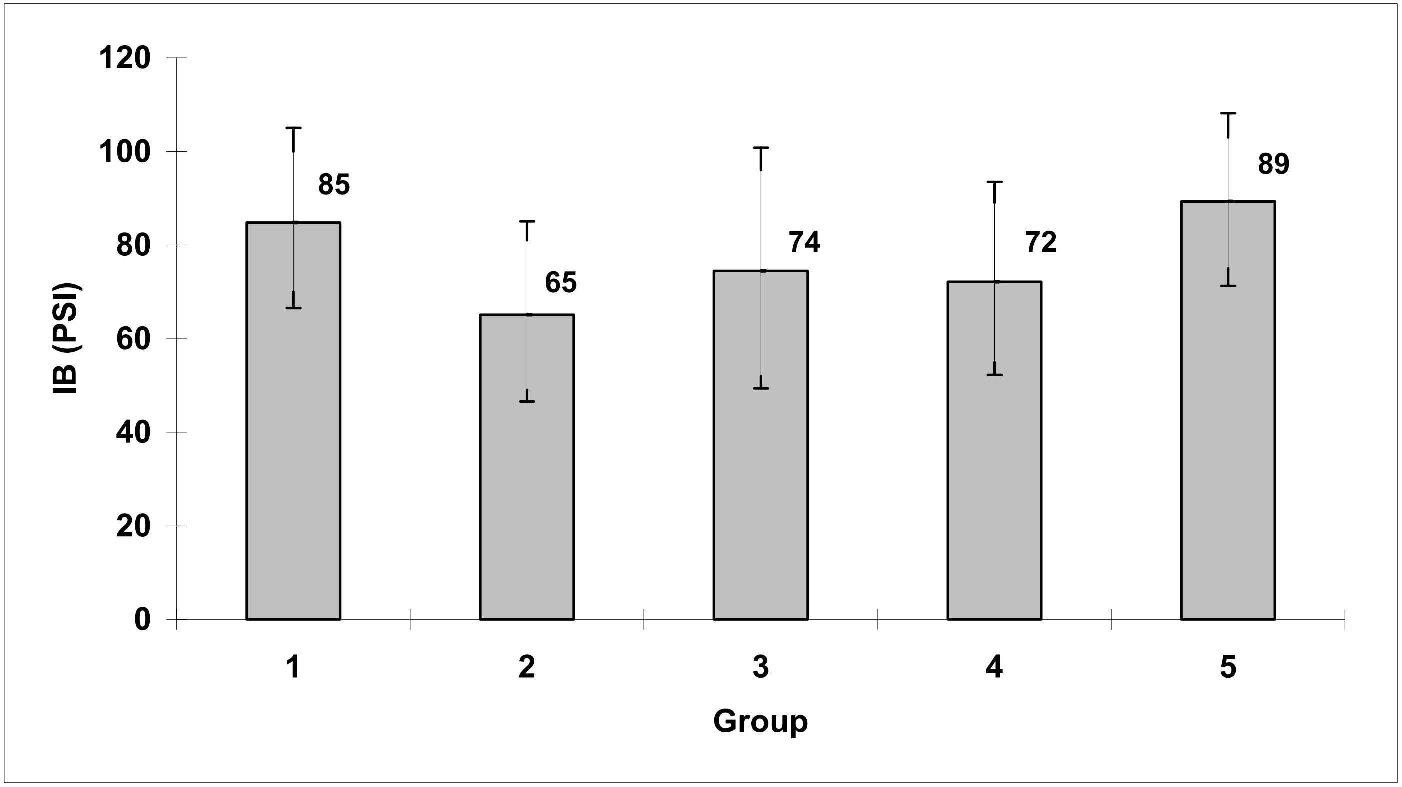


Figure 5. IB tests of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

swell test was detected by analysis of variance, while the linear expansion and water absorption were found to be insignificant (Table 6). Also, a simple linear regression model was summarized of thickness swell (Table 7). There are little discernable trends of linear expansion and water absorption.

- Statistical analyses

Analysis of variance (ANOVA) was tested for all the bending strength, internal bond, and dimensional stabilities. ANOVA results are listed in Table 6. The IB tests for both standard and ODVPS specimens are highly significant at $\alpha = 0.01$. The ANOVA of thickness swell presents significance at $\alpha = 0.05$. The rest of tests indicate no significance of ANOVA tests.

The Dunnett comparison and regression analysis were applied to the tests with significance of ANOVA. Dunnett test is used to test comparisons of all treatments against a control. In this particular experiment, all treatments are different ratios of flakeboard contents, and the Group 5 with 100% untreated virgin wood content is considered as a control. The results show no significant difference for all the treatment versus the control for each property (Table 7).

Regression tests were started as simple linear regression. If the test was not significant for slope, then polynomial regression was tested. The test results are summarized in Table 8. The test for thickness swell was stopped at simple linear regression with significance of p-value for slope. The tests for IB indicate that there is significance in the quadratic model. However, no significance was

detected for IB-ODVPS in quadratic regression. In the higher regression test, such as cubic regression, the results for IB-ODVPS were far from significance. A quadratic regression model for IB-ODVPS was also reported in Table 8.

The regression models give quantitative relationships between treatments, in term of percent of CCA-treated wood content, IB, IB-ODVPS, and thickness swell, respectively. The significant model for thickness swell and IB were plotted in Figures 17 and 18. Also, the regression analysis allows more degrees of freedom and power in the test.

Variance proportion test was also performed. The results listed in Table 9 show that the proportion of covariance of panel (Group) to pure error for all the properties of panels. All the ratios are no more than one, which means the variance of panel nested in treatments (groups) is a less effect in the test. In the other words, the effect of each specimen inside individual panels plays a major role. These results infer that heterogeneous sub-samples in each panel were tested.

4.2. Decay Resistance

Soil decay test results showed decreased decay resistance for both white rot and brown rot fungus as the flakeboard CCA-treated wood proportion diminished in the flakeboard (Table 10 and Figure 19).

- <u>Brown rot</u>

The significant difference among each treatment (group) was found by ANOVA at a high level (Table 6). The tests indicate that all the weight loss of

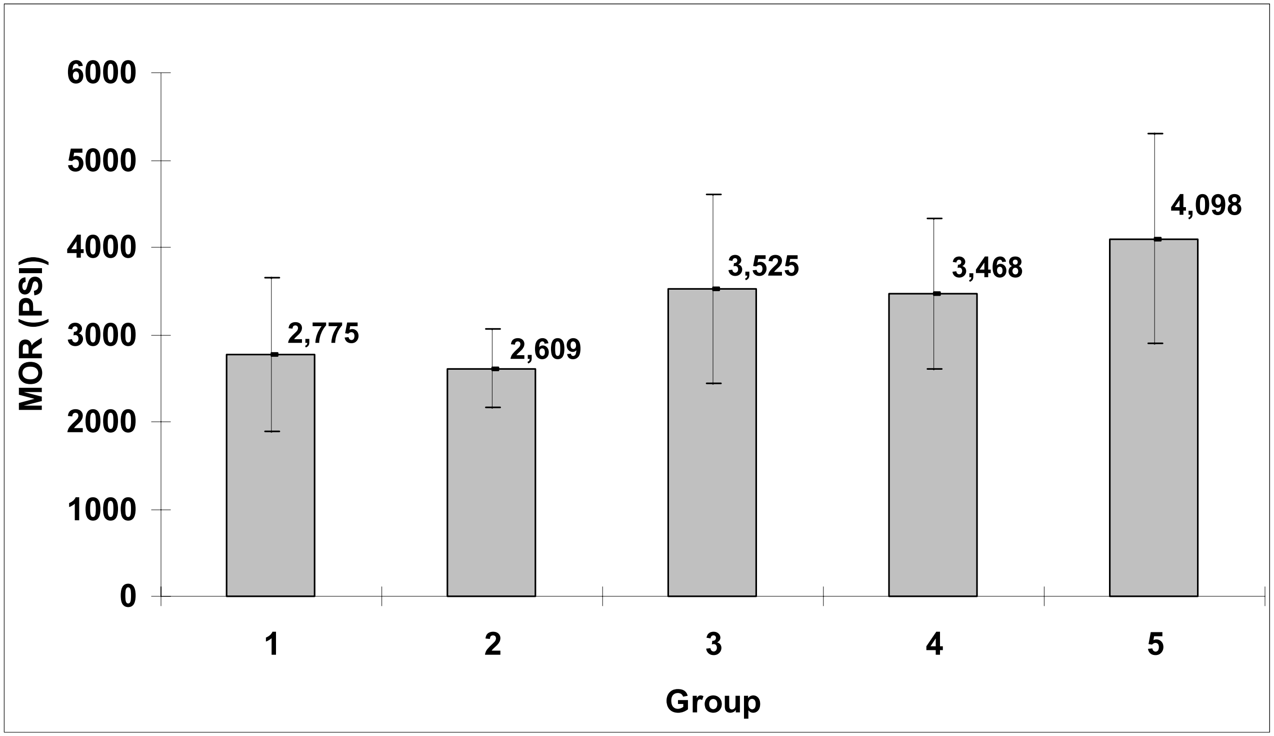


Figure 6. MOR tests after ODVPS of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

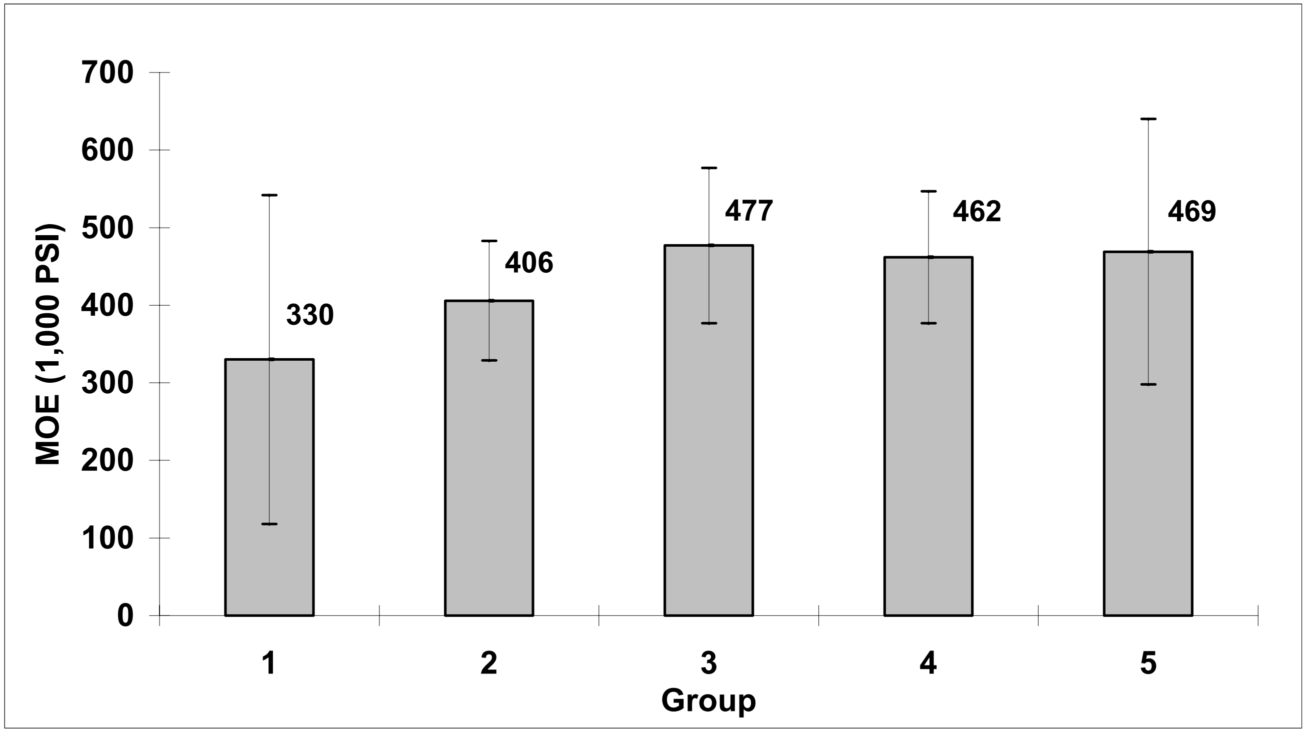


Figure 7. MOE tests after ODVPS of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

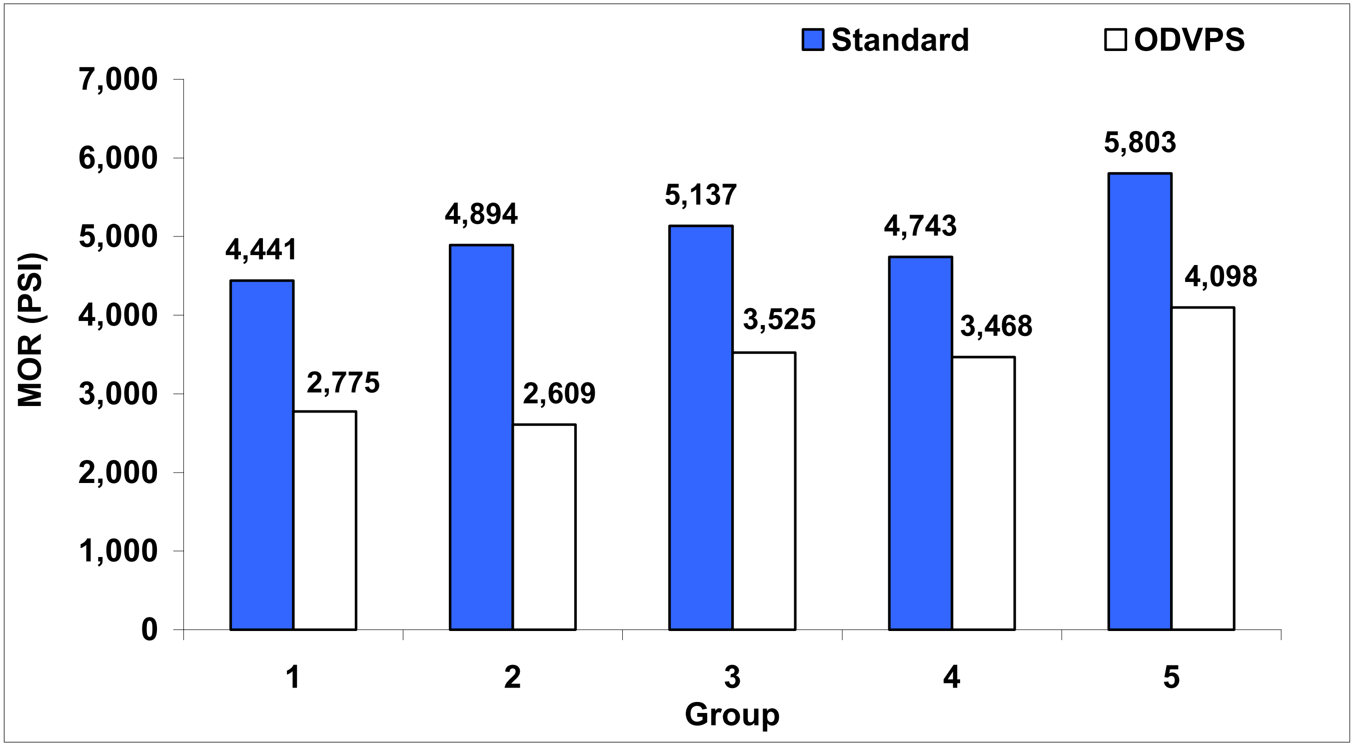


Figure 8. Contrast of MOR between standard and ODVPS of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

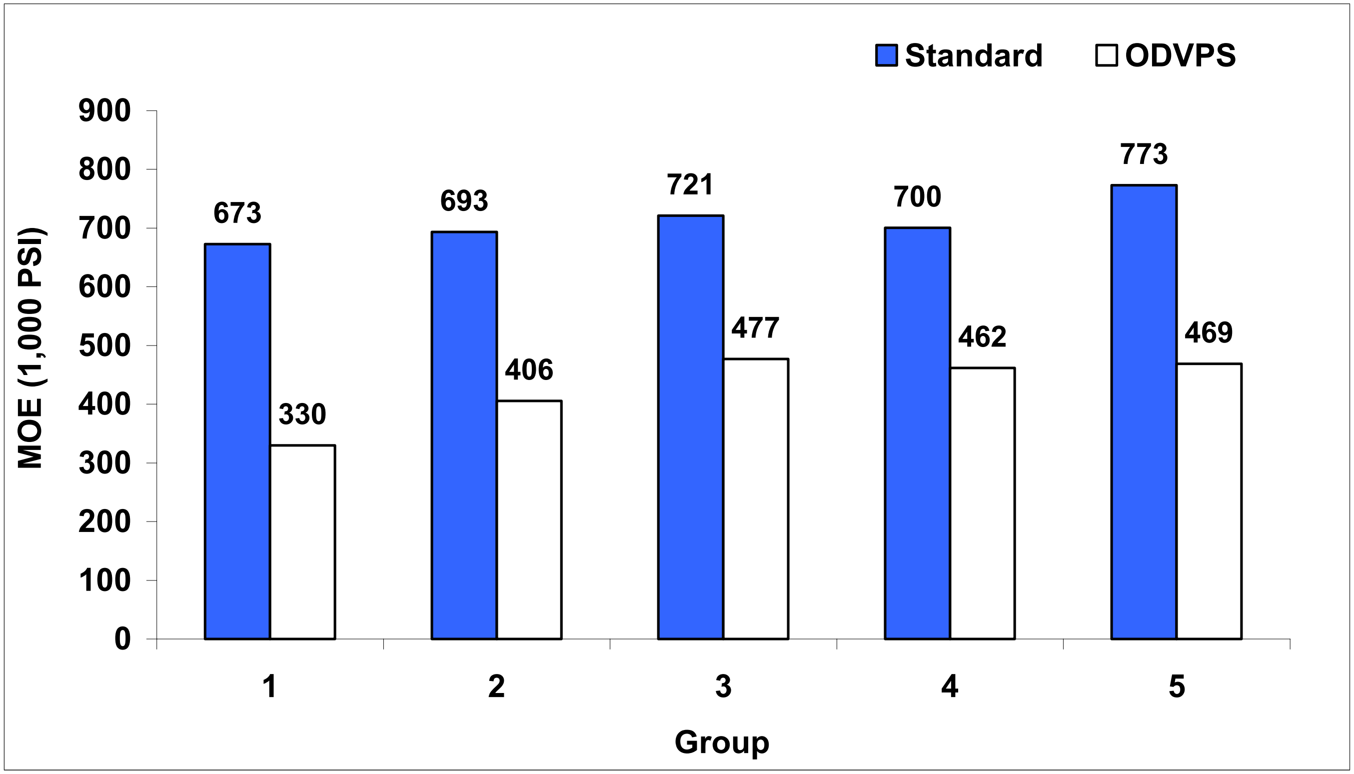


Figure 9. Contrast of MOE between standard and ODVPS of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

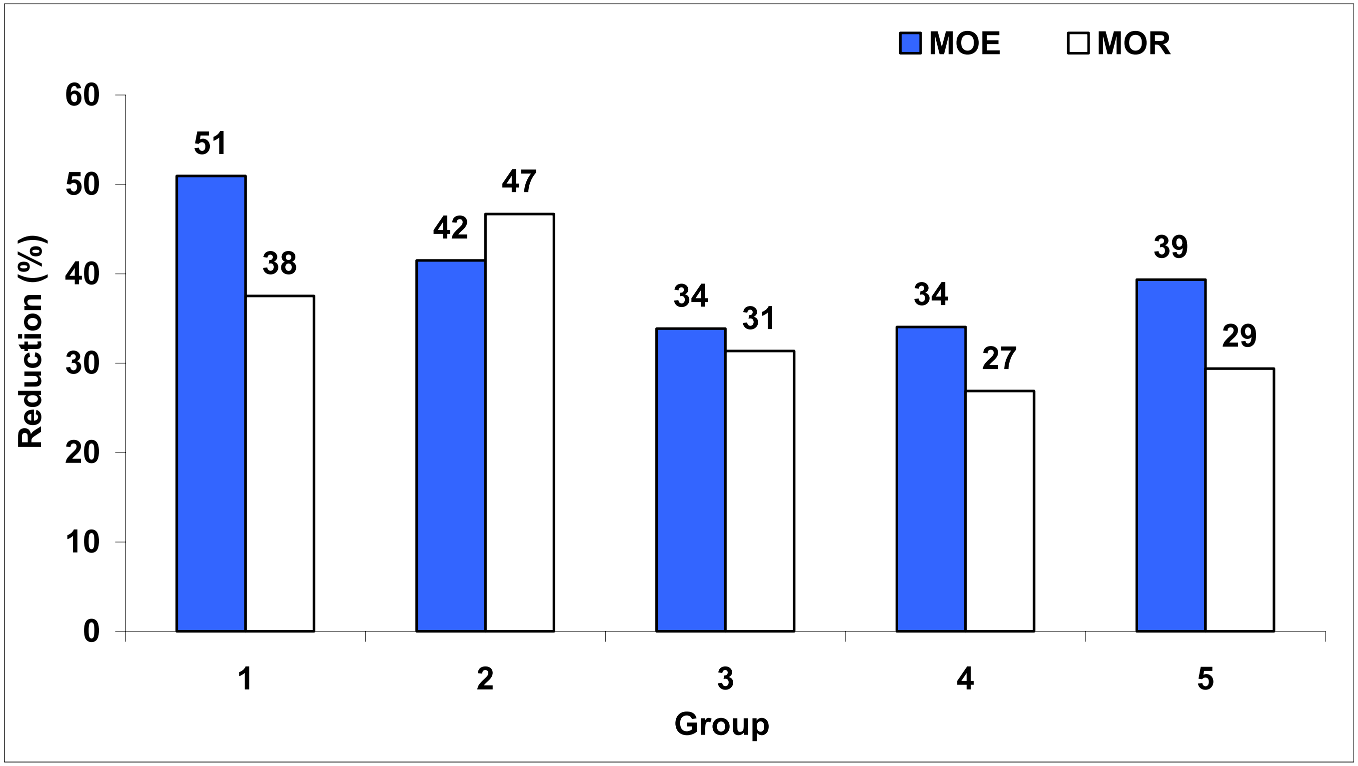


Figure 10. Bending strength reduction after ODVPS of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

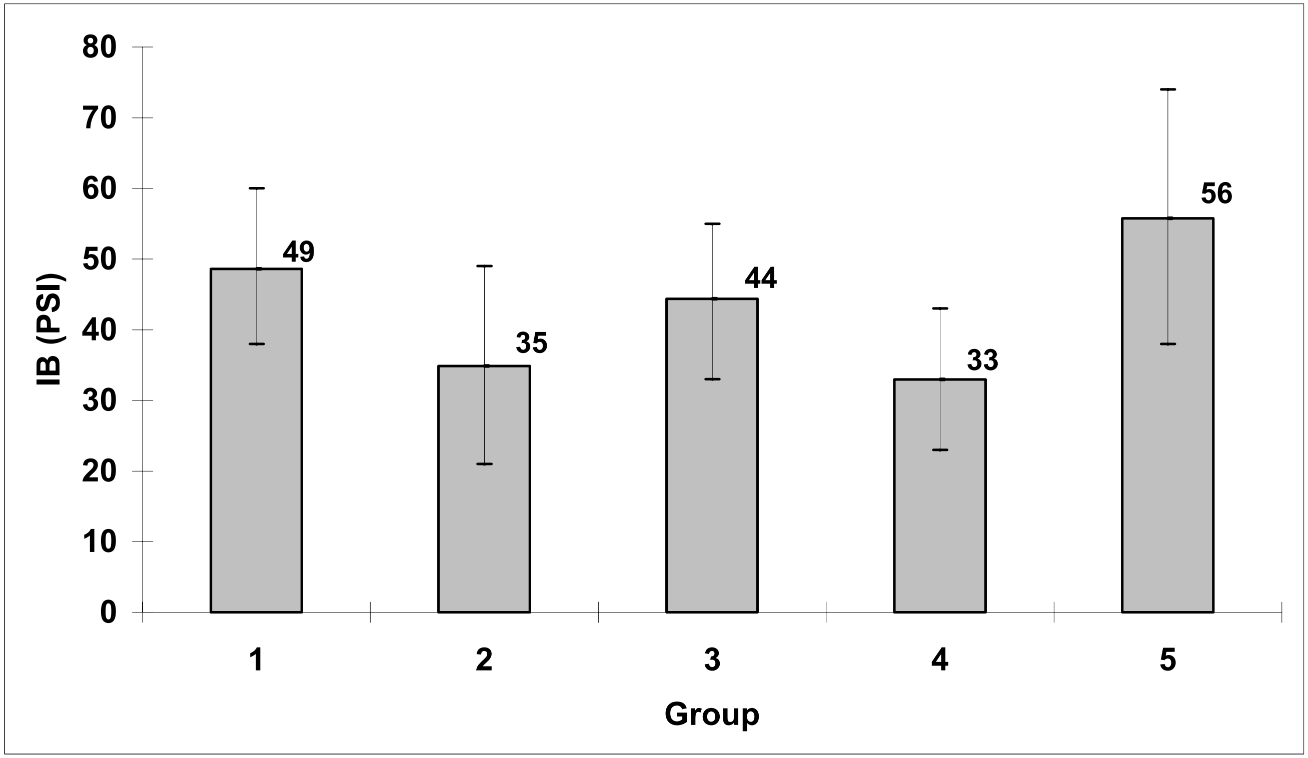


Figure 11. IB tests after ODVPS of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

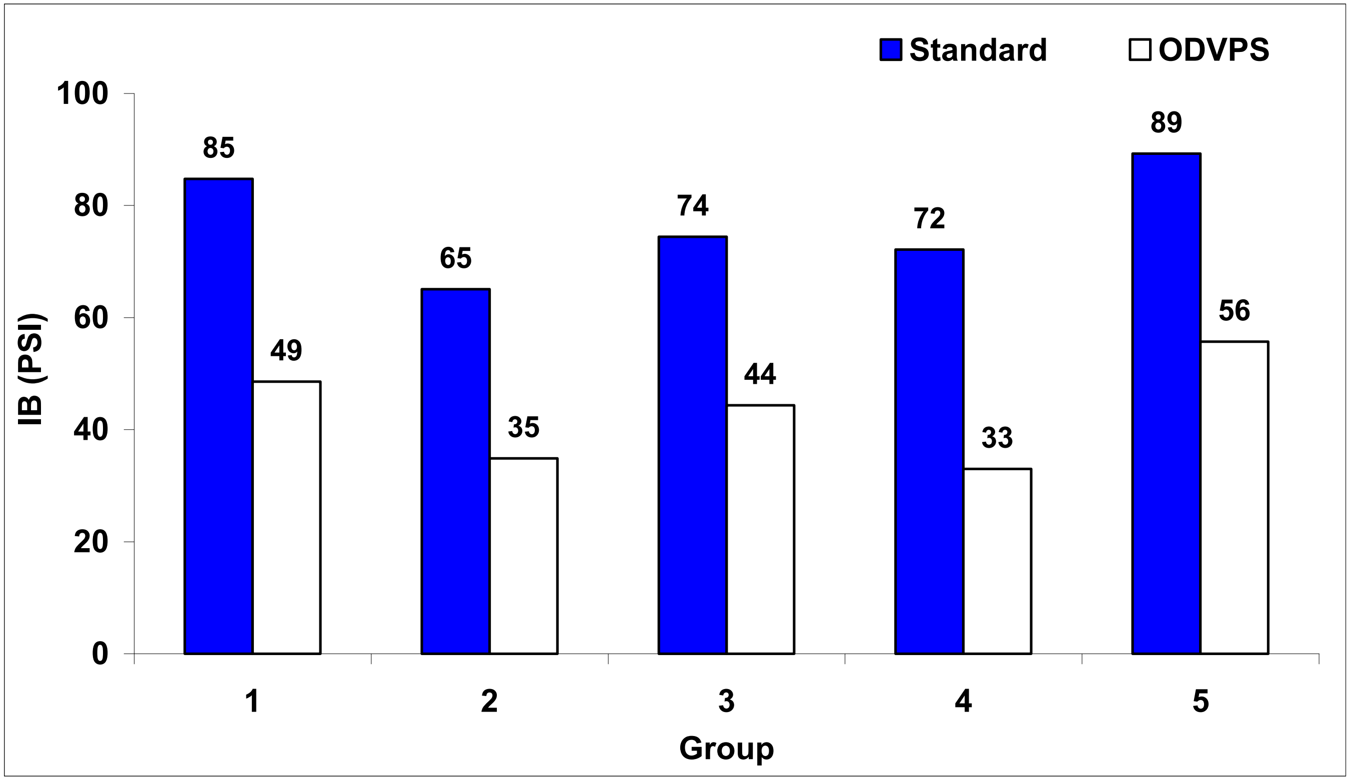


Figure 12. Contrast of IB between standard and ODVPS of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

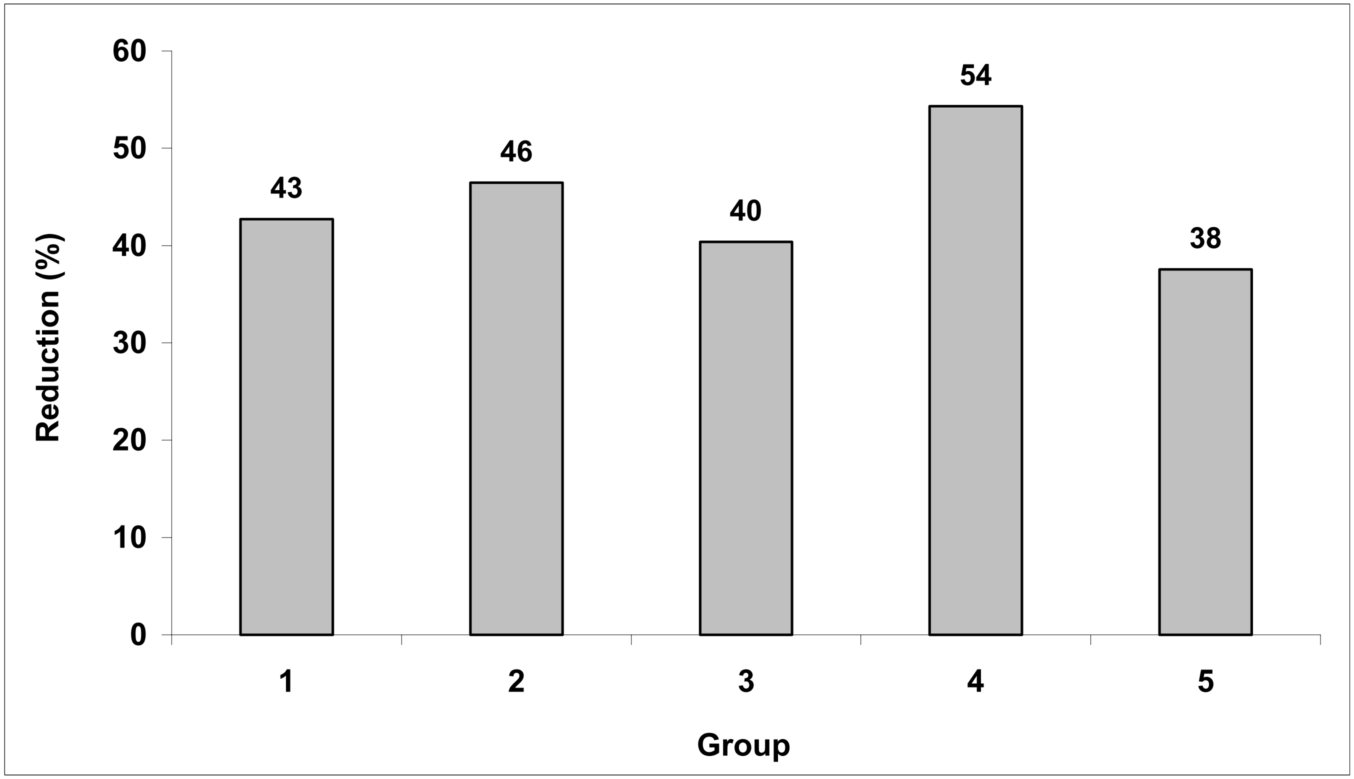


Figure 13. IB reduction after ODVPS of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

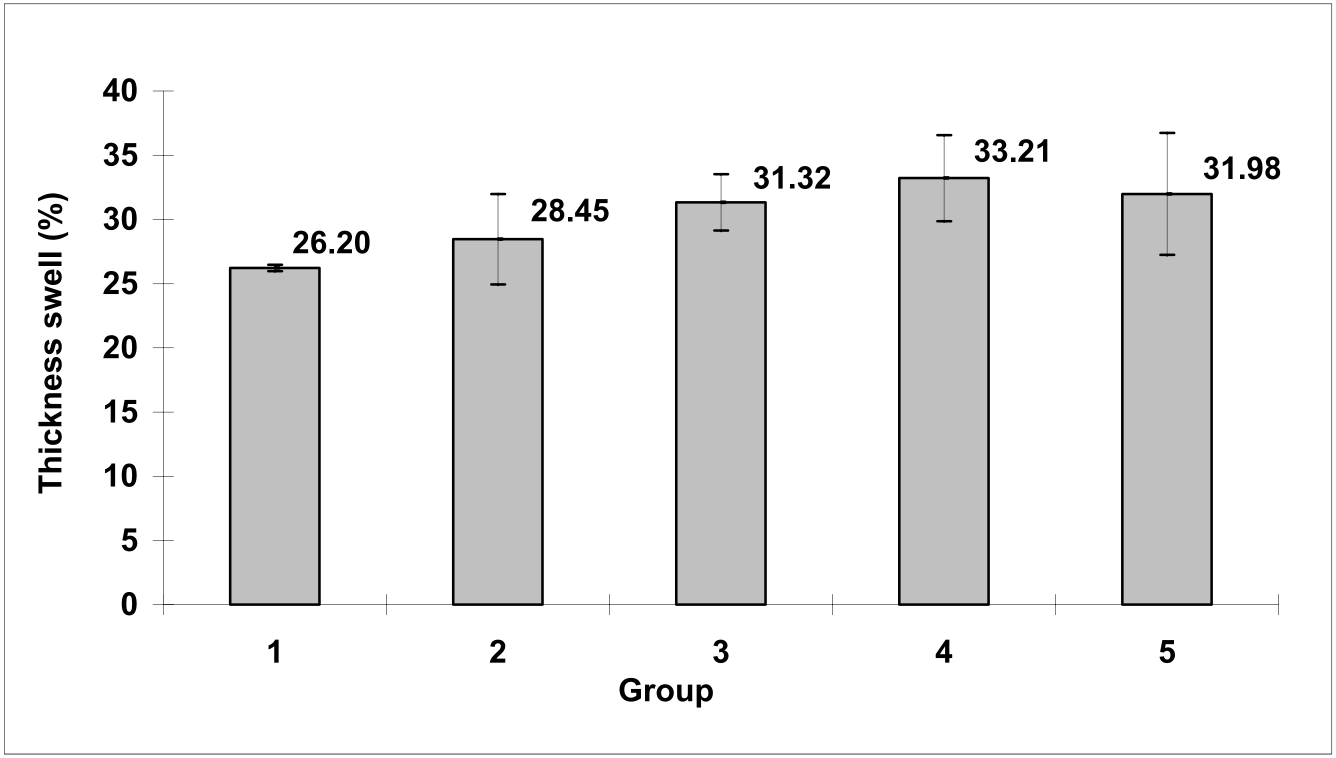


Figure 14. Thickness swell of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1 100% recycled CCA-treated wood.
Group 2 75% recycled CCA-treated wood, 25% virgin wood.
Group 3 50% recycled CCA-treated wood, 50% virgin wood.
Group 4 25% recycled CCA-treated wood, 75% virgin wood.
Group 5 100% virgin wood.

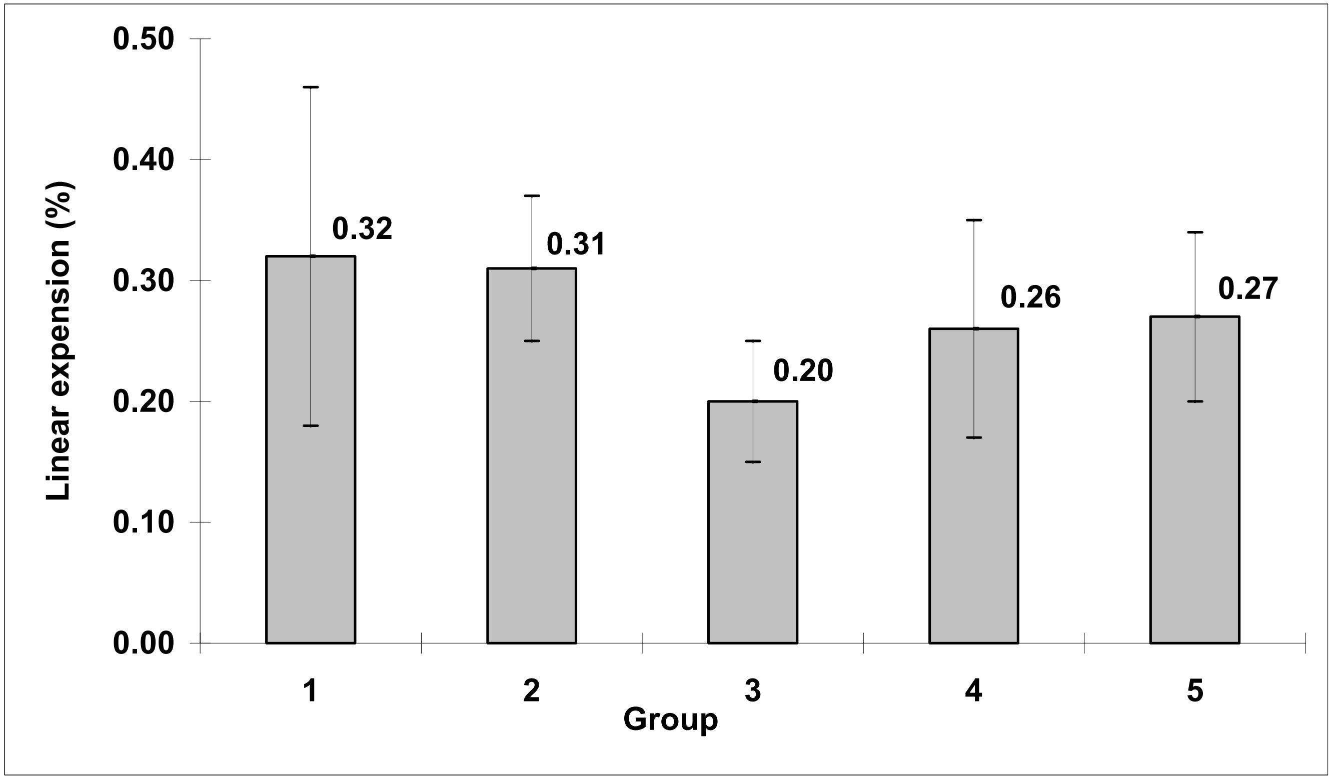


Figure 15. Linear expansion of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

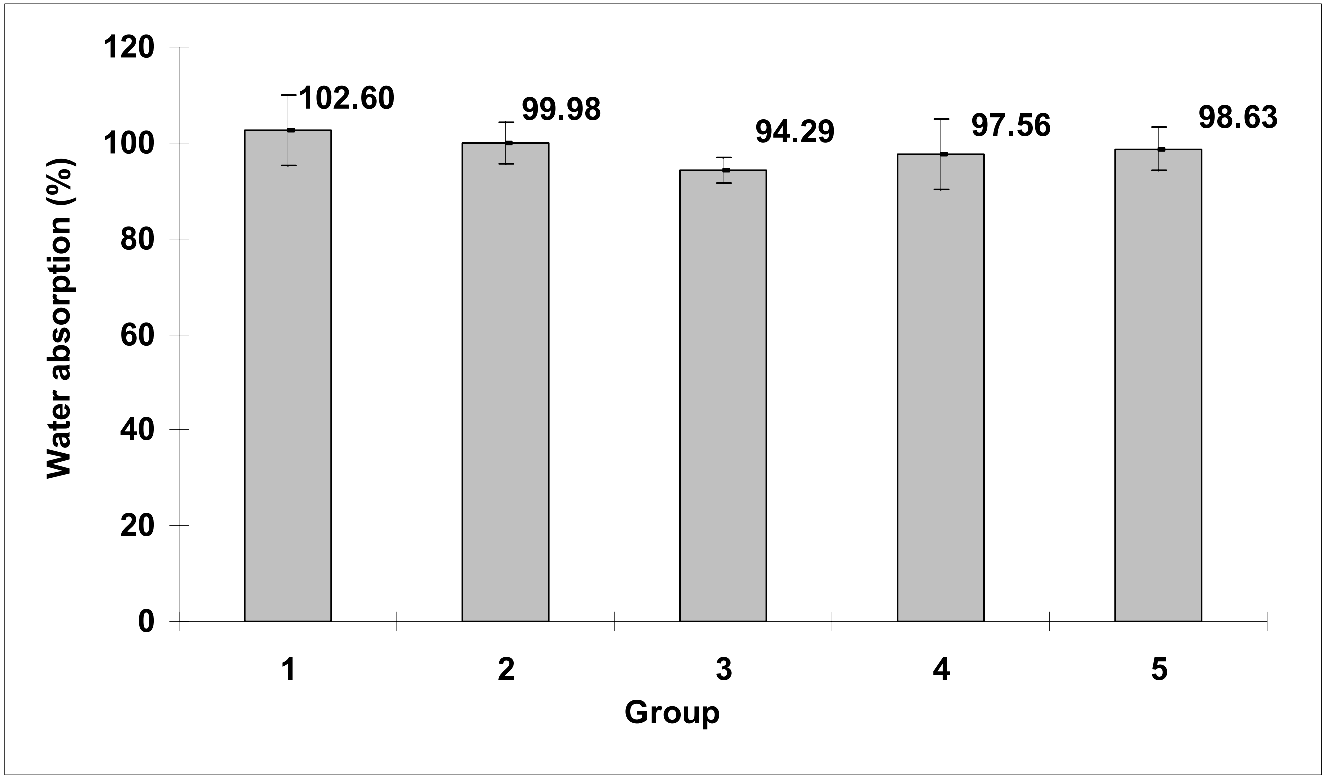


Figure 16. Water absorption of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

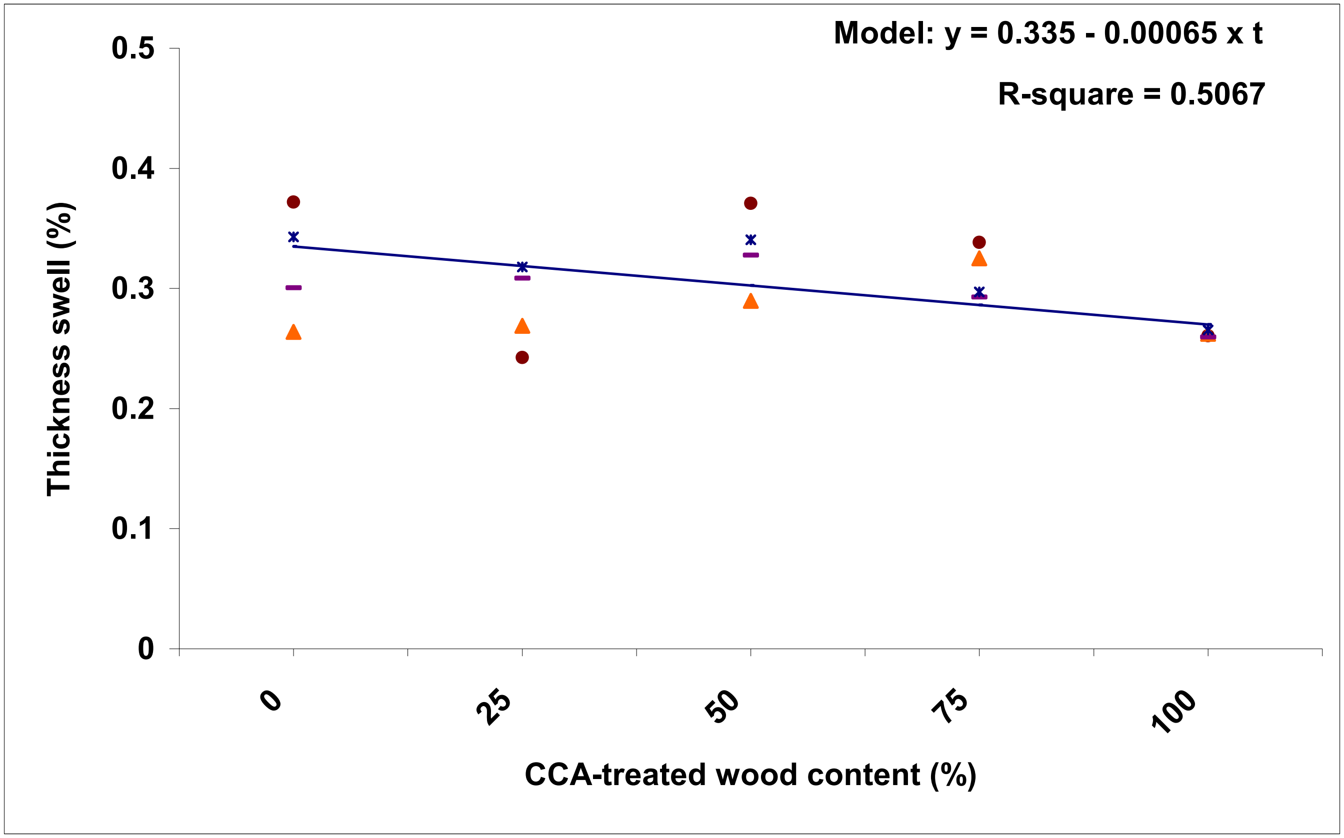


Figure 17. Simple linear regression plot of thickness swell of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

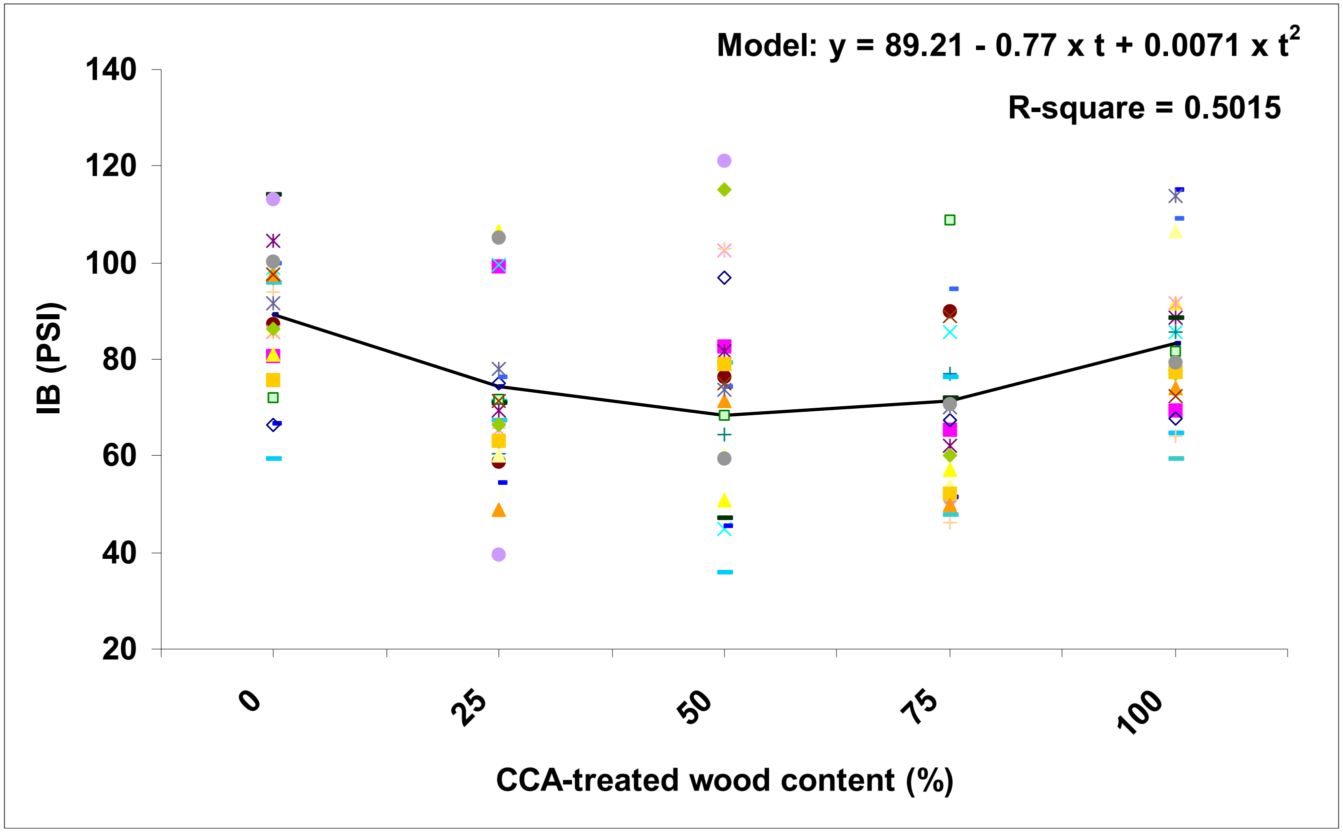


Figure 18. Quadratic regression plot of IB of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Table 7. Dunnet tests for IB, IB-ODVPS and thickness swell of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Sources	Group Comparison	Difference Between Means	Simultaneous 95% Confidence Limits	
IB	Group 1 vs. Group 5	-4.490	-36.793	27.813
	Group 3 vs. Group 5	-14.844	-47.147	17.459
	Group 2 vs. Group 5	-17.115	-49.418	15.188
	Group 4 vs. Group 5	-24.188	-56.490	8.115
IB-ODVPS	Group 1 vs. Group 5	-6.651	-36.279	22.976
	Group 3 vs. Group 5	-10.863	-40.490	18.765
	Group 2 vs. Group 5	-20.802	-50.903	9.299
	Group 4 vs. Group 5	-22.250	-51.878	7.377
Thickness swell	Group 4 vs. Group 5	0.01228	-0.08615	0.11072
	Group 3 vs. Group 5	-0.00659	-0.10503	0.09184
	Group 2 vs. Group 5	-0.03539	-0.13382	0.06305
	Group 1 vs. Group 5	-0.05781	-0.15624	0.04062

* Denotes significance at < 0.05.

Table 8. Regression analyses of properties of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Sources	Regression models	P-value for coefficient	R-square
Thickness swell	$y = 0.335 - 0.00065 \times t$ [a]	t: 0.0209*	0.5067
IB	$y = 89.21 - 0.77 \times t + 0.0071 \times t^2$	t: 0.0328* t^2: 0.0388*	0.5015
IB - ODVPS [b]	$y = 53.08 - 0.64 \times t + 0.0059$ [d] $\times t^2$	t: 0.0775 t^2: 0.0864	0.3792

* Denotes significance at < 0.05.
[a] Represents treatment, in terms of the percent of CCA-treated wood.
[b] The tests after an oven dry vacuum-pressure-oak treatment.

Table 9. Covariance parameter estimates of physical and mechanical properties of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Sources	Cov Parm[a]	Estimate[b]	Ratio[c]
MOE	Panel(Group)	144000	0.39
	Residual	367821	
MOR	Panel(Group)	0	0
	Residual	893531	
MOE-ODVPS	Panel(Group)	0	0
	Residual	1.946E10	
MOR-ODVPS	Panel(Group)	0	0
	Residual	869231	
IB	Panel(Group)	64.9	0.25
	Residual	257.2	
IB-ODVPS	Panel(Group)	54.7	0.38
	Residual	143.8	
Thickness swell	Panel(Group)	0.000437	0.60
	Residual	0.000730	
Linear expansion	Panel(Group)	0	≅ 1
	Residual	7.88-E7	
Water absorption	Panel(Group)	0	0
	Residual	0.003054	

[a] Covariance parameter.
[b] Covariance parameter estimate.
[c] Covariance parameter versus pure error (residual),
Ratio = covariance of Panel(Group) / Residual.

flakeboards subjected to brown rot were lower than the fresh southern pine sapwood (Group 6), even Group 5 with 100% virgin wood. Regarding the CCA-treated guardrail samples (Group 7), the weight losses of Group 3 – 5 had significant difference, whereas the Group 1 and 2 had not. It was revealed that the higher the CCA-treated wood content in the furnish of flakeboard, the better the

decay resistance. Meanwhile, PF resin has some decay resistance due to its high pH value (Schmidt *et al.* 1978), therefore, this can explain why Group 5 with no CCA-treated wood content had a less weight loss than control Group 7.

- <u>White rot</u>

The difference of each group subjected to white rot was also tested using ANOVA (Table 6). All panel groups (Groups 1 – 5) presented significantly better decay resistance than the fresh southern pine group. To contrast guard rail specimens (Group7), Groups 3 and 5 resulted in significantly lower decay resistance. But, there was no significant difference was found in Groups 1, 2 and 4. In the other word, the Groups 1, 2 and 4 had similar decay resistance to white rot as did the guard rail.

- <u>Summary</u>

Decay resistance was less than 10% and 18% for Groups 1-5 subjected to white rot and brow rot, respectively (Table 10). These values are much lower than the weight losses of untreated southern pine, which has 12.01% and 44.72% subjected to white rot and brown rot, separately. These results point out that flakeboards fabricated from recycled CCA-treated flakes are imparted higher decay resistance. Since, brown rot is the most destructive type of wood decay for softwoods, it could explain the higher weight loss for test blocks subjected to brown rot (Schmidt *et al.* 1983).

Soil block test offers a decay hazard more severe than would be encountered by flakeboard in most service situations. Previous results indicate

that in a high decay hazard structural flakeboard should be well protected against decay to insure continued strength in service (Schmidt *et al.* 1983).

4.3. CCA Retention

Copper oxide, Chromium trioxide and arsenic pentoxide retention in the flakeboard samples is shown in Table 11 and Figure 20. The elemental concentration of CCA gradually decreases from Group 1 to Group 5.

Table 11 and Figure 20 report the Copper oxide, Chromium trioxide and arsenic pentoxide retention in CCA-treated guardrail posts from different horizontal positions – outer, middle and inner, and vertical positions - top, middle and bottom. The retention and distribution of each three metallic content are varied much for individual posts, as well as at different vertical and horizontal positions.

Table 10. Average weight loss of two control groups (fresh southern pine and out-of-service guard rail) and flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood after exposure to white rot and brow rot in a soil block test.

Group	Weight Loss (%)	
	White Rot	Brown Rot
1	6.80 (1.80)[c]	5.37 (1.11)
2	6.54 (0.68)	6.17 (2.05)
3	9.08 (1.07)	11.06 (3.01)
4	6.64 (0.69)	10.90 (6.99)
5	9.05 (1.29)	17.93 (9.38)
6[a]	12.01 (1.27)	44.72 (5.53)
7[b]	7.36 (0.87)	6.30 (1.14)

[a] Group 6: Control group - Fresh southern pine sapwood.
[b] Group 7: Out-off-service CCA-treated southern pine guard rail.
[c] Values in parentheses are standard deviations.

Table 11. CCA retention of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

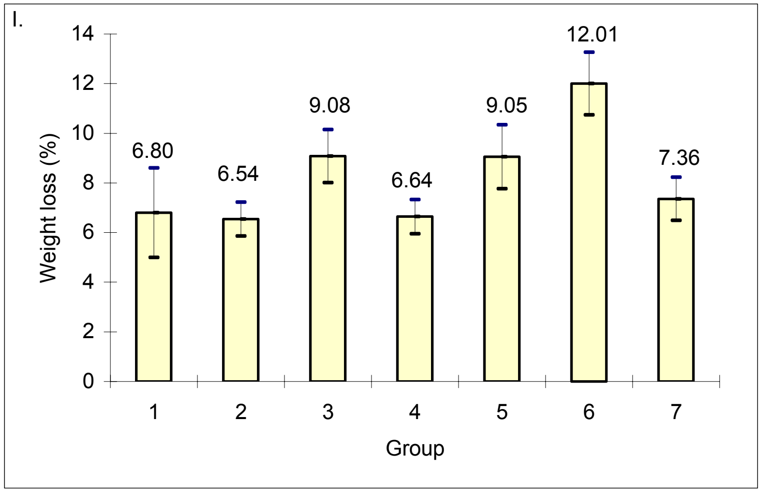
Group[a]	Copper Oxide (pcf)	Chromium Trioxide (pcf)	Arsenic Pentoxide (pcf)	Total (pcf)
1	0.11	0.29	0.22	0.61
2	0.08	0.21	0.16	0.46
3	0.05	0.12	0.09	0.26
4	0.03	0.07	0.05	0.15
5	0.00	0.00	0.00	0.00

[a] Group 1 100% recycled CCA-treated wood.
Group 2 75% recycled CCA-treated wood, 25% virgin wood.
Group 3 50% recycled CCA-treated wood, 50% virgin wood.
Group 4 25% recycled CCA-treated wood, 75% virgin wood.
Group 5 100% virgin wood.

4.4. CCA Leaching

CCA leaching tests were performed over a 28-day period, during which 3 leaching samples were taken for each experimental panel group at day-1, day-7, day-14, day-21, and day-28 (Figures 22-25).

The leaching amount of CCA sequentially declined with time for all four groups that contained CCA-treated wood. After 14 days, the leaching rate tends to be stable at a lower level. The phenomenon is as similar to results found by Munson and Kamkem (1998). Lebow (1996) found that the leaching of CCA treated wood occurs primarily during the initial stages of placement into service. As expected, the amount of leaching for each group was found to be related to the original CCA concentration of each group.



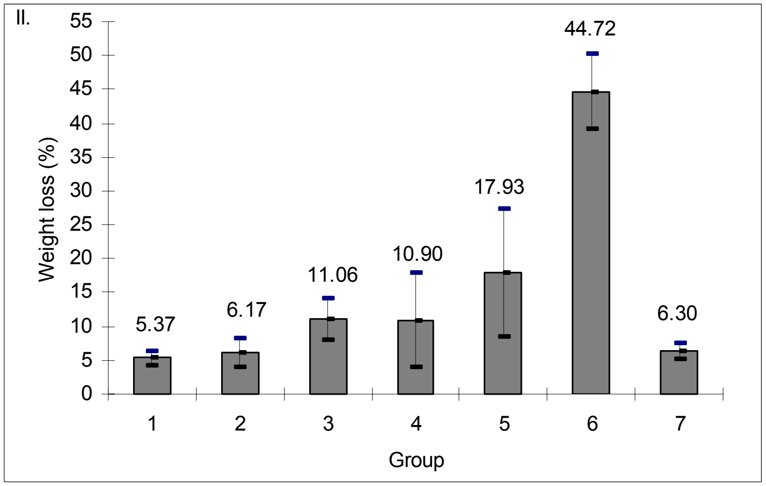


Figure 19. Soil block decay tests of exposure to (I) white rot fungi, (II) brown rot fungi of two control groups (fresh southern pine and out-of-service guard rail) and flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.
Group 6	Fresh southern pine sapwood (Control group).
Group 7	Out of service CCA-treated southern pine guard rail (Control group).

Table 12. CCA retention of three selected guardrail posts from different horizontal (outer, middle, and inner) and vertical (top, middle, and bottom) locations.

Post no.	Top[a]				Middle[a]				Bottom[a]			
	Copper	Chromium	Arsenic	Total	Copper	Chromium	Arsenic	Total	Copper	Chromium	Arsenic	Total
2-O [b]	0.159	0.332	0.293	0.784	0.204	0.507	0.328	1.039	0.125	0.346	0.216	0.687
2-M [b]	0.027	0.098	0.094	0.219	0.041	0.096	0.049	0.186	0.027	0.057	0.030	0.114
2-I [b]	0.034	0.111	0.113	0.258	0.012	0.004	0.002	0.018	0.014	0.013	0.003	0.030
8-O [b]	0.019	0.086	0.059	0.164	0.148	0.345	0.237	0.730	0.108	0.284	0.148	0.540
8-M [b]	0.001	0.009	0.005	0.015	0.093	0.231	0.237	0.561	0.097	0.261	0.161	0.519
8-I [b]	0.042	0.147	0.158	0.347	0.133	0.360	0.395	0.888	0.043	0.105	0.057	0.205
10-O [b]	0.096	0.254	0.246	0.596	0.111	0.322	0.261	0.694	0.125	0.283	0.186	0.594
10-M [b]	0.098	0.237	0.230	0.565	0.038	0.124	0.094	0.256	0.038	0.095	0.057	0.190
10-I [b]	0.090	0.188	0.192	0.470	0.006	0.038	0.015	0.059	0.011	0.006	0.003	0.020

[a] Vertical locations.
[b] Horizontal locations: O – outer, M – middle, and I – inner.

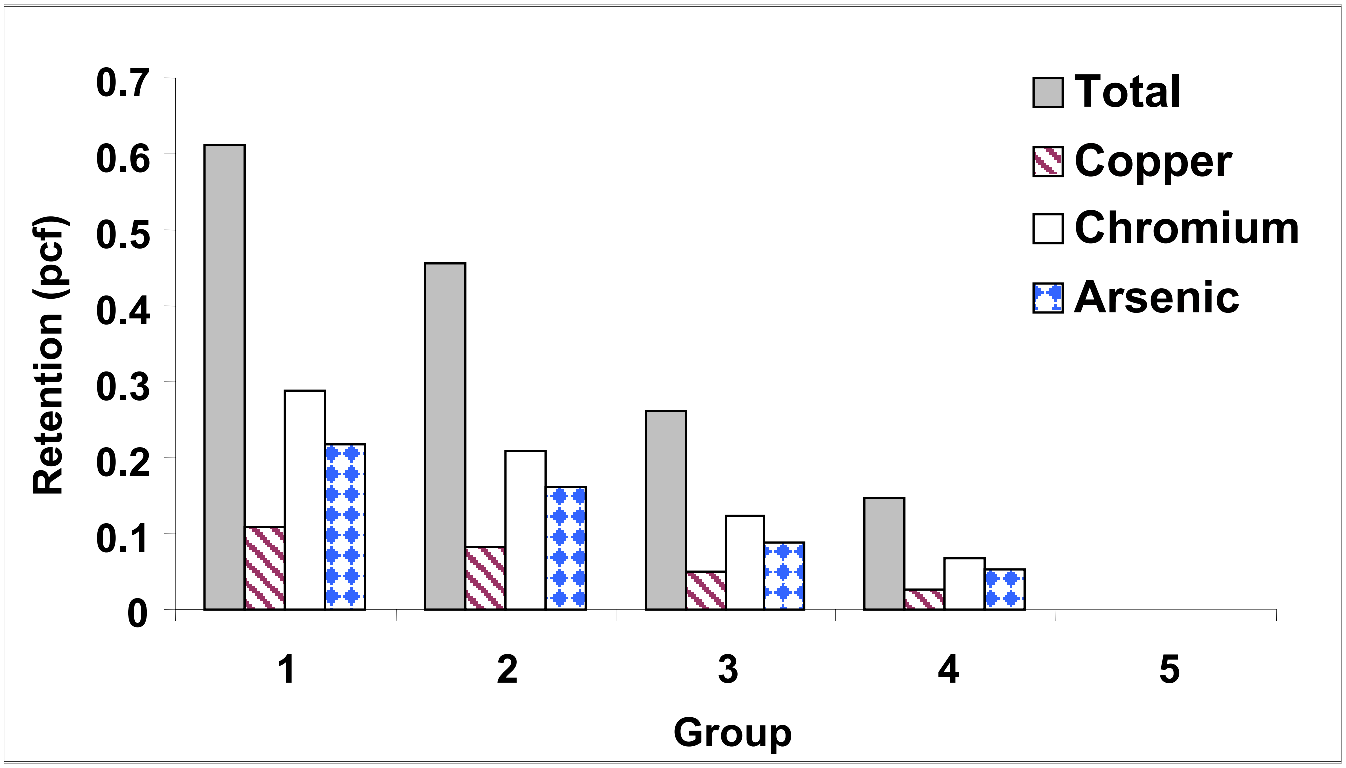


Figure 20. CCA retention of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

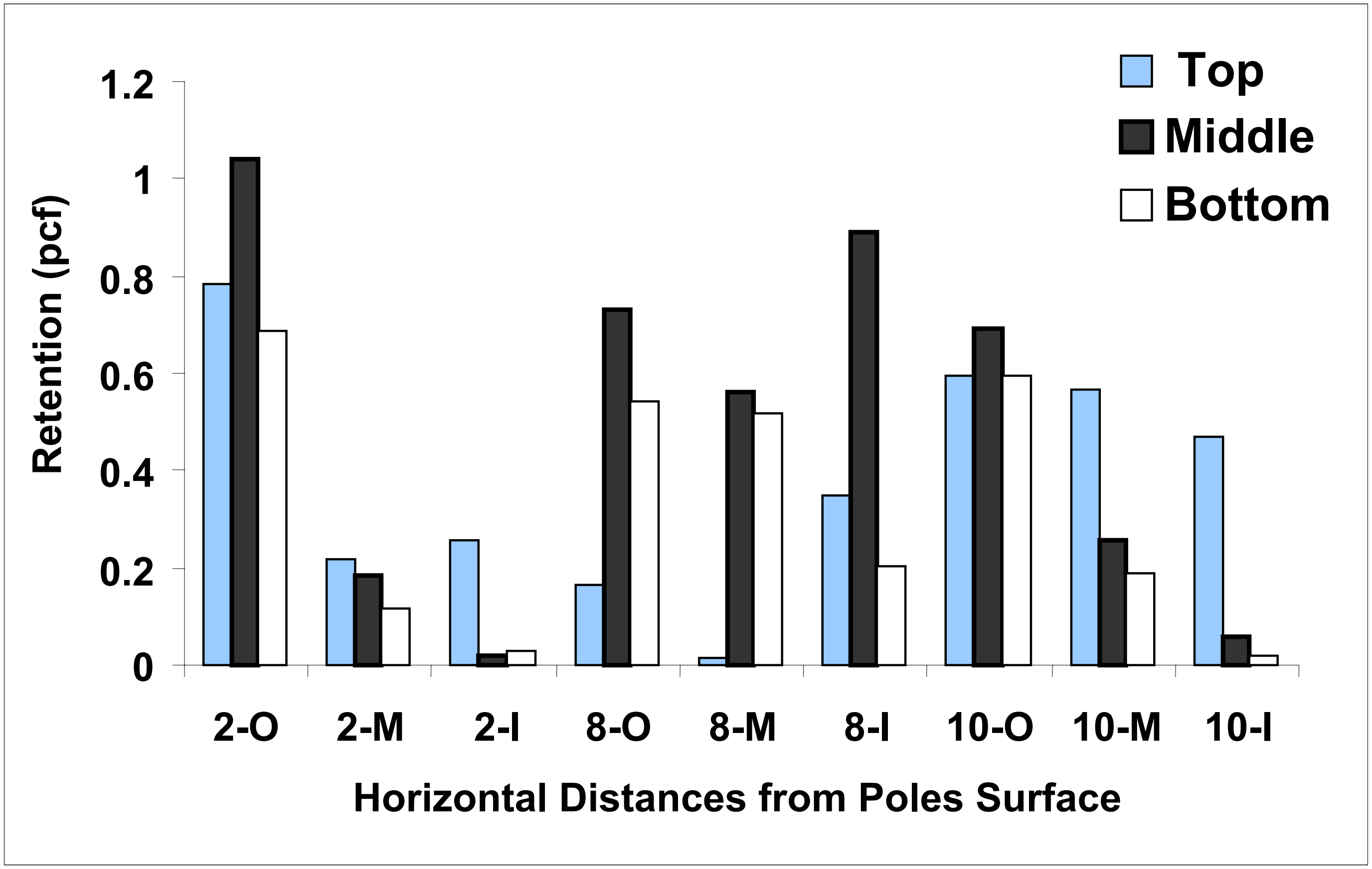


Figure 21. CCA retention of guardrail posts from different horizontal (outer, middle, and inner) and vertical (top, middle, and bottom) locations.

O – outer.
M – middle.
I – inner.

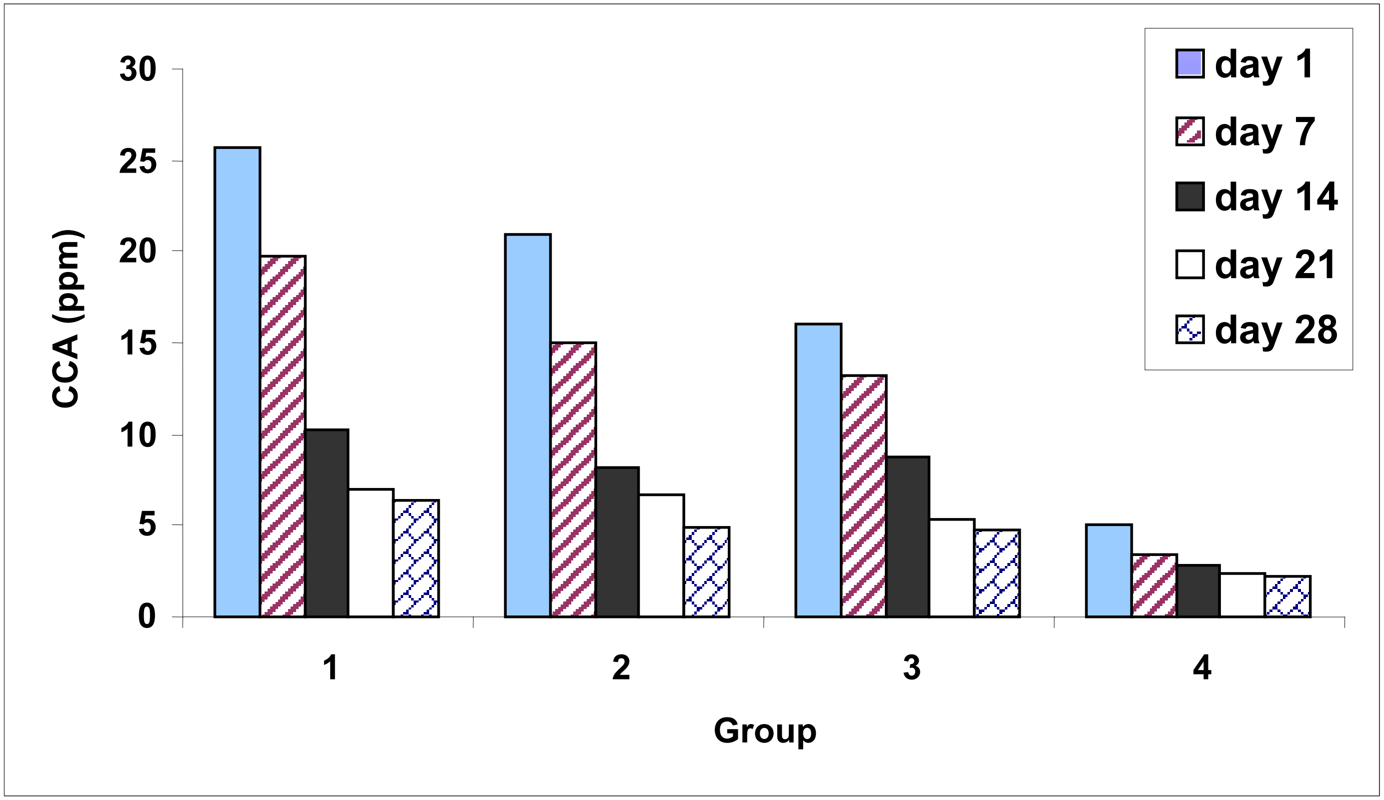


Figure 22. Total CCA leaching of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

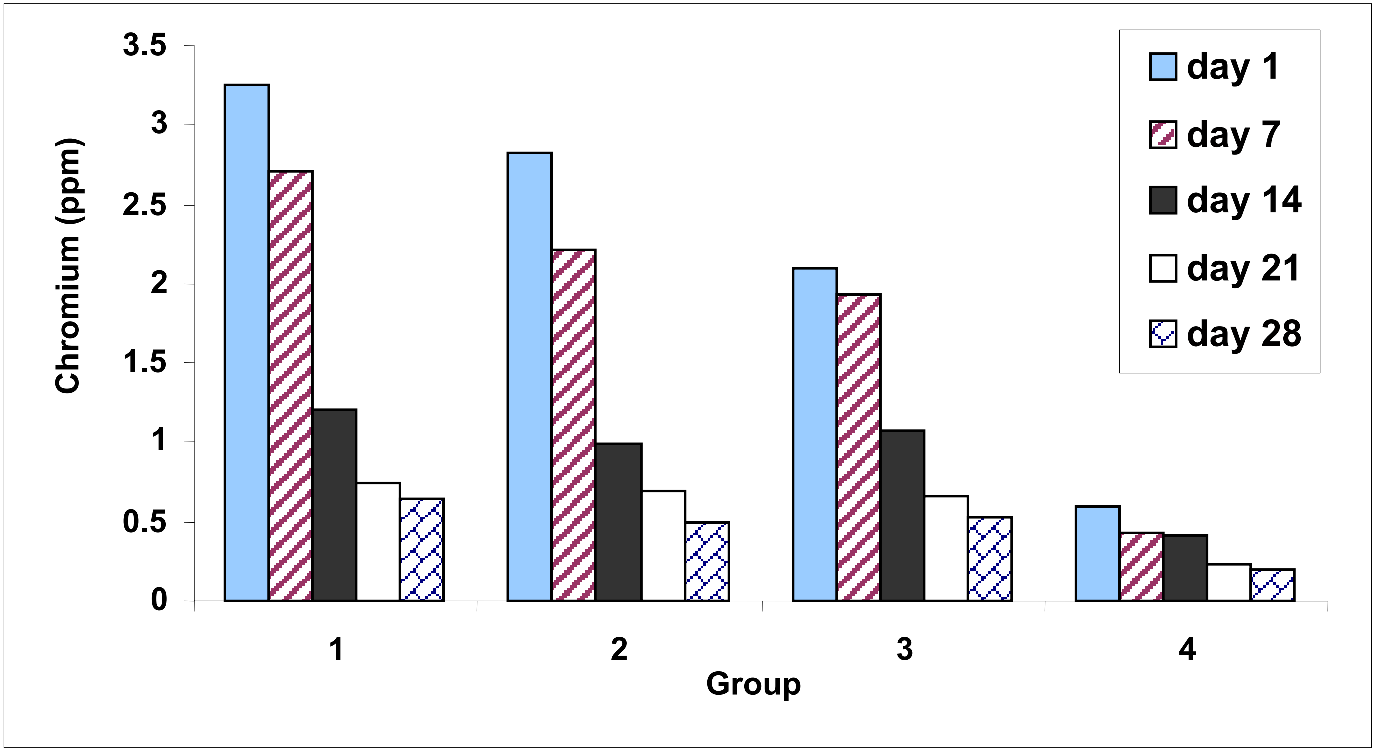


Figure 23. Chromium leaching of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

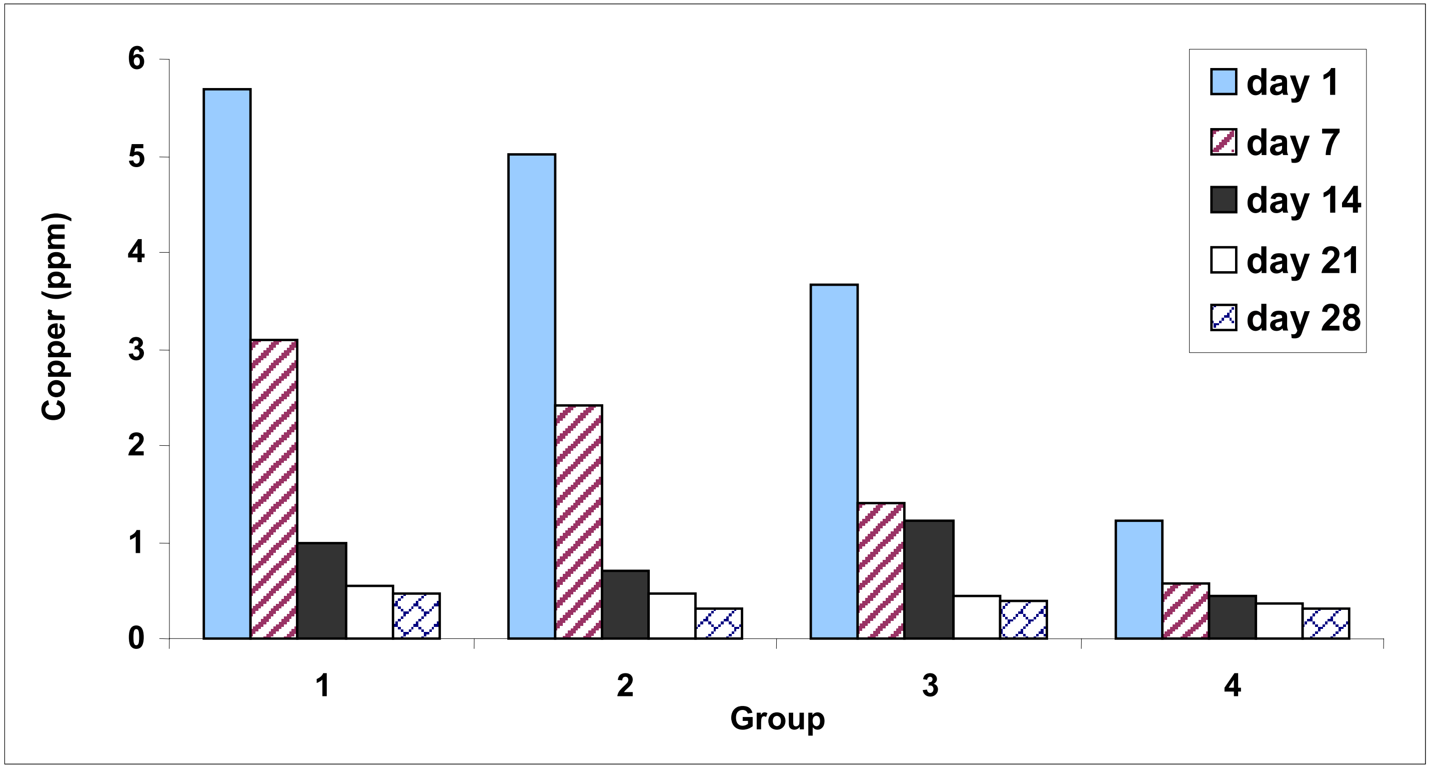


Figure 24. Copper leaching of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

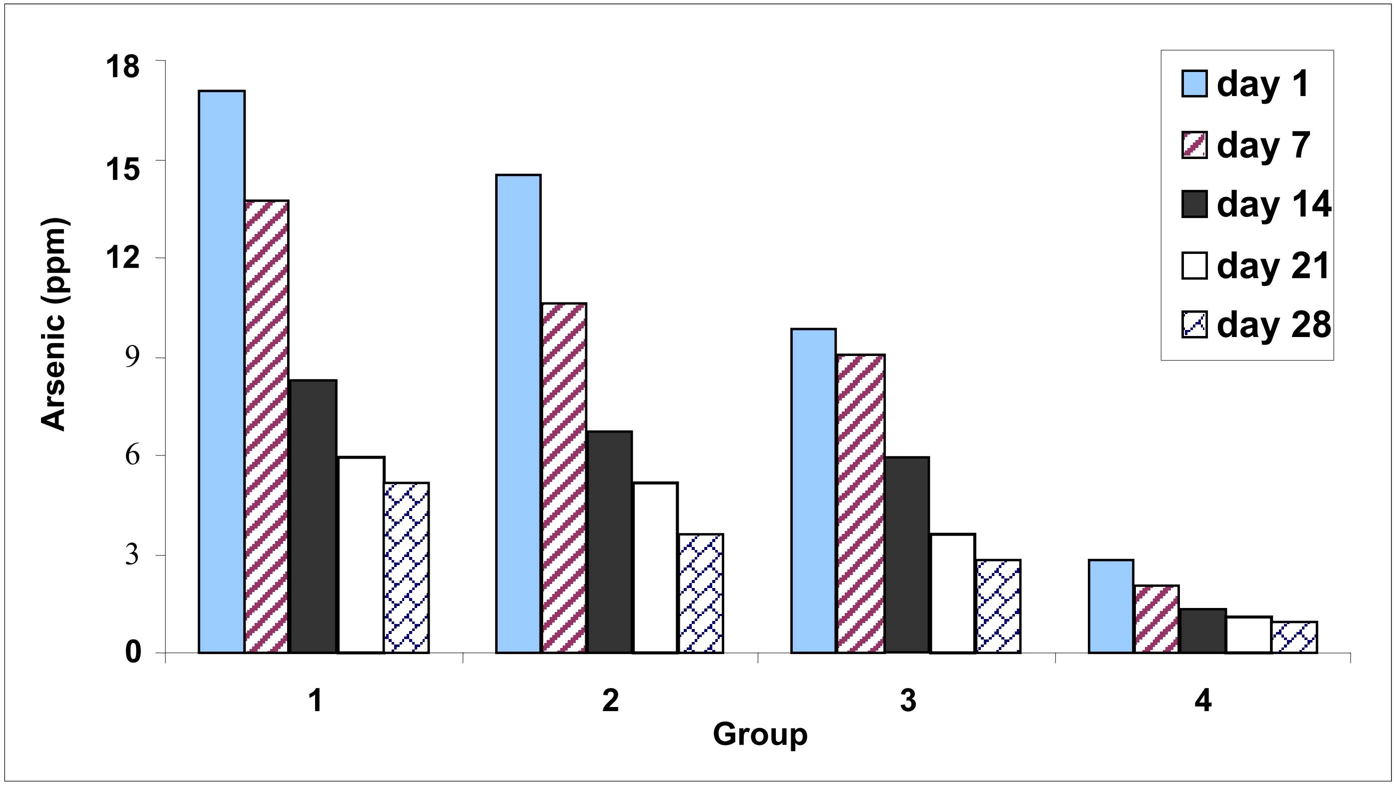


Figure 25. Arsenic leaching of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Group 1	100% recycled CCA-treated wood.
Group 2	75% recycled CCA-treated wood, 25% virgin wood.
Group 3	50% recycled CCA-treated wood, 50% virgin wood.
Group 4	25% recycled CCA-treated wood, 75% virgin wood.
Group 5	100% virgin wood.

4.5. Supplementary Experiments

Because the IB of flakeboard panels yielded results that were much different as was found for MOR and MOE, supplementary experiments were conducted to examine possible explanations. Following are the general test procedures and results are summarized.

- Microscopic analyses

High magnification micrographs were taken with a CAMBRIDGE 260 STEREOSCAN Scanning Electron Microscope (SEM). The CCA-treated flake and untreated flakes were coated with gold for SEM.

All SEM specimens were viewed at a magnification over 4,000 ×. The cell lumen of CCA-treated sapwood was fully covered by hemispherically shaped, uniformed sized, mixed deposits of copper, chromium, and arsenic (Figure 26). However, it was difficult to identify preservative deposits from heartwood cell lumens (Figure 27). Untreated southern pine cell lumens were visually very smooth with natural warts (Figure 28). The observations are similar to those made by Vick (1992).

The experimental flakeboard panels were fabricated from flakes produced from recycled CCA-treated guardrail posts, which contained mixtures of sapwood and heartwood. The possibility existed of a non-uniform distribution of flakes from the different locations of the posts.

- Wettability

Contact angles were measured to evaluate the wettability of flake surface by PF adhesive (Malds and Kamden 1999, Roliadi *et al.* 2000a). Experimental

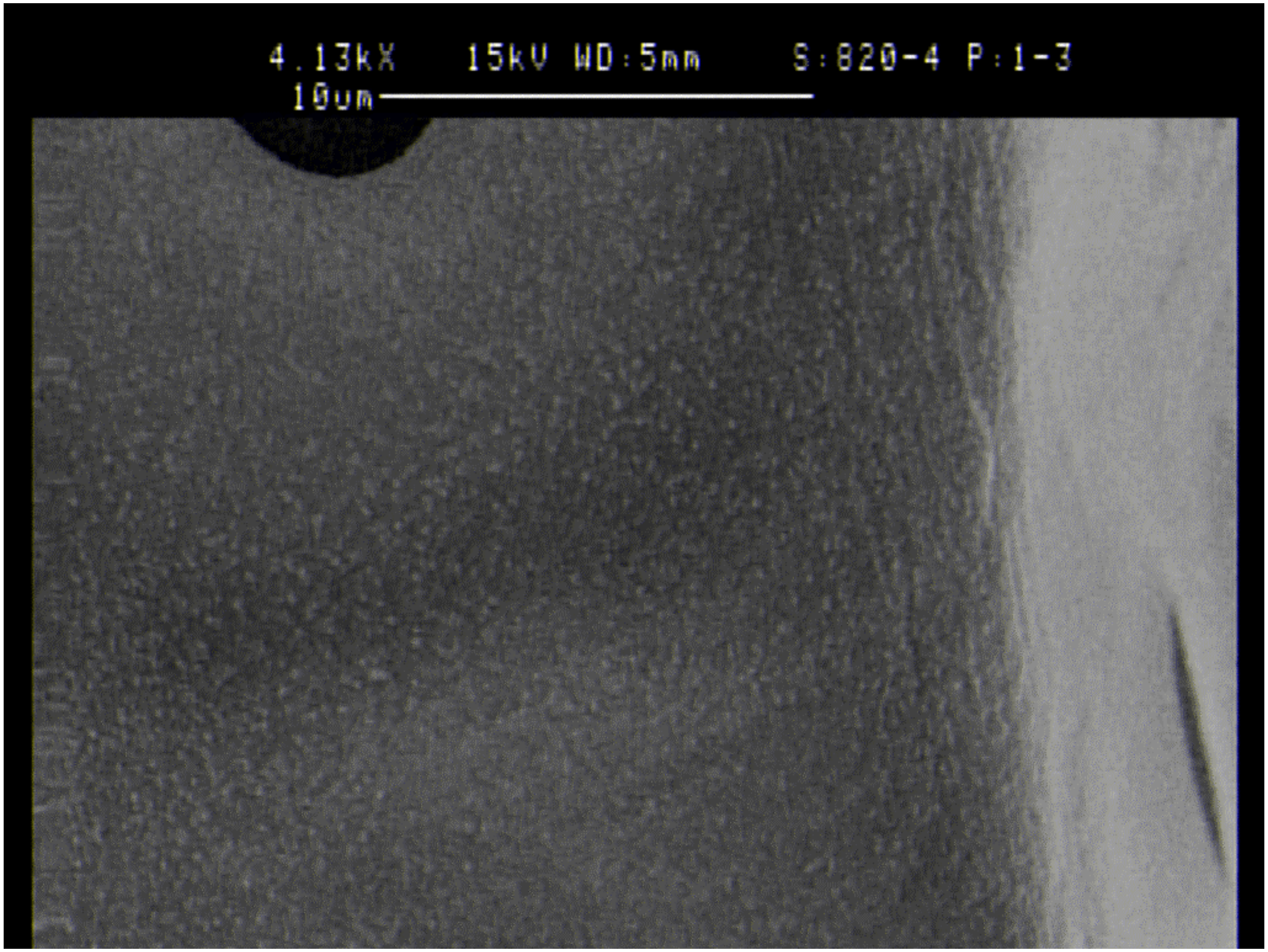


Figure 26. Scanning electron micrograph of the surface of a cell lumen of a CCA-treated wood flake of sapwood with hemispherically shaped chromium, copper, and arsenic.

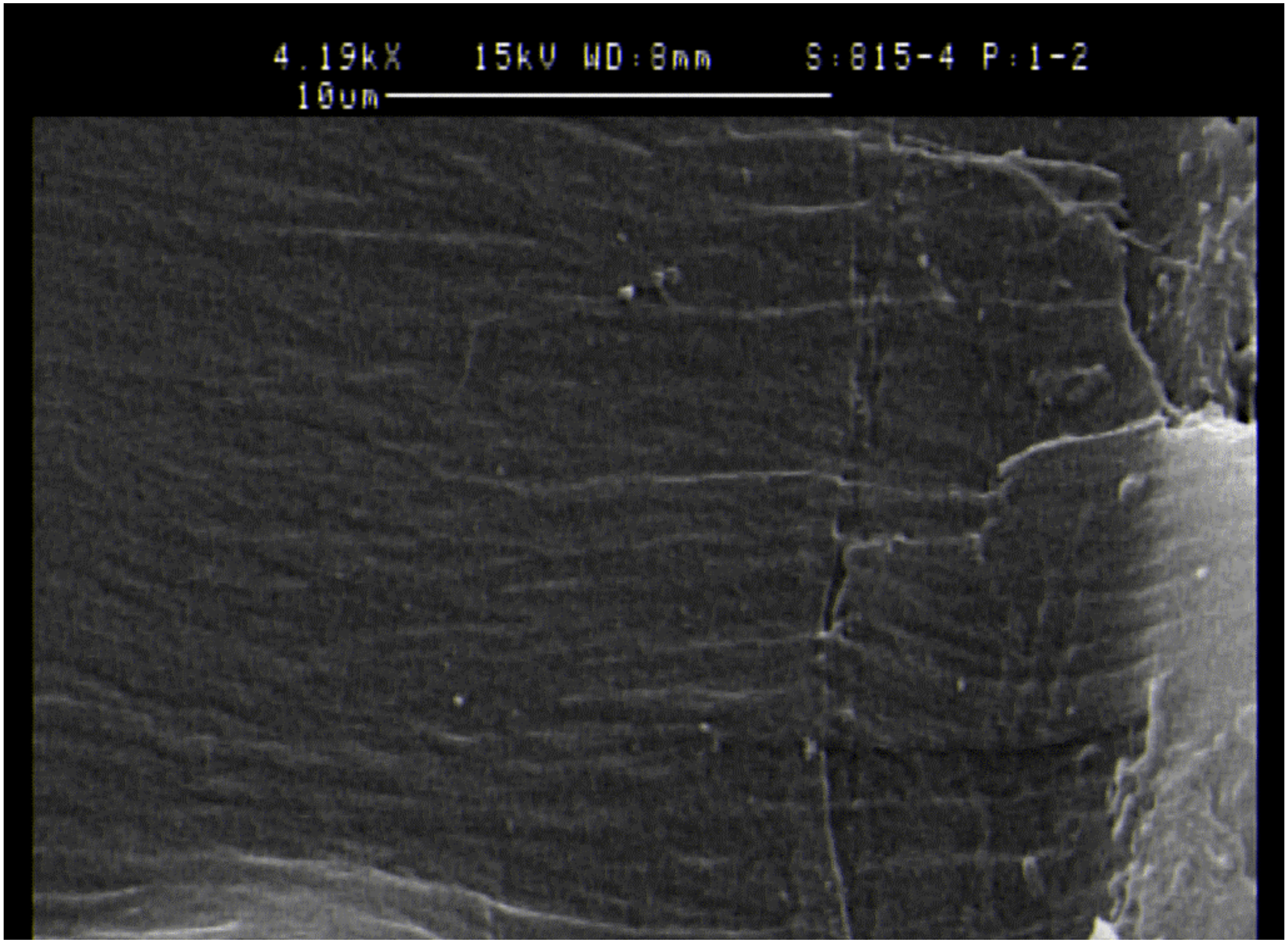


Figure 27. Scanning electron micrograph of the surface of a cell lumen of a CCA-treated wood flake of heartwood.

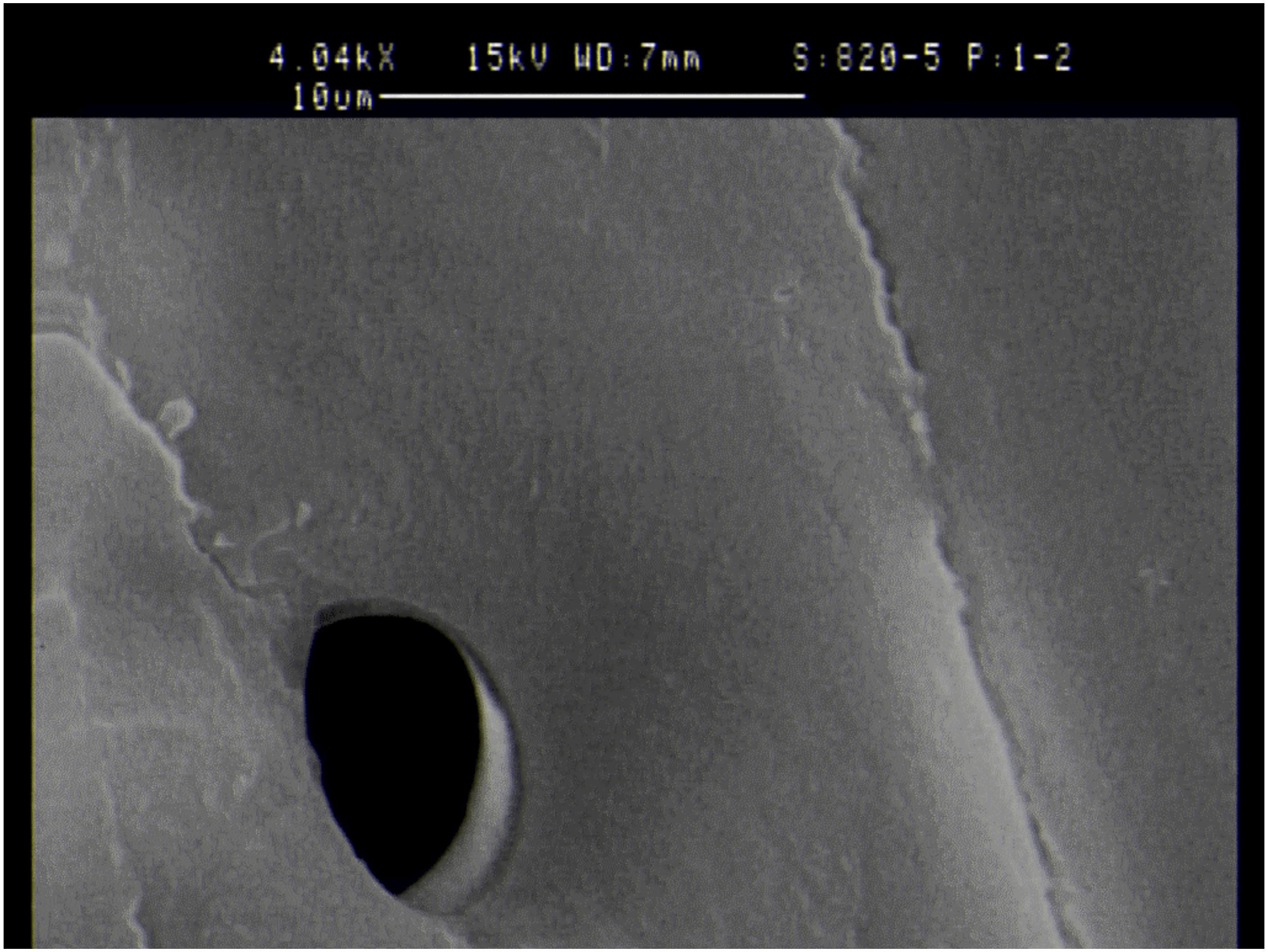


Figure 28. Scanning electron micrograph of smooth surface of a cell lumen from an untreated southern pine flake.

CCA-treated flakes and untreated southern pine flakes were used as specimens for contact angle measurements. The flakes were either conditioned at ambient room conditions or ovendried at 217 ± 4°F (102 ± 2°C) for 24 hours. The wettability was determined on both the earlywood and latewood of each flake. The contact angles were measured with a microscope equipped with a goniometer eyepiece. The microscope tube was arranged horizontally. The specimen was placed on the stage, and a 1-ml syringe generated a small droplet (0.05-ml) of PF resin, the same resin as used for flakeboard fabrication.

The contact angles of CCA-treated wood are higher than those of untreated wood (Table 9). This difference is statistically significant. The higher contact angels of untreated wood indicate better penetration of resin into wood (Malds and Kamden 1999).

Table 13. Comparison of contact angles of CCA-treated recycled southern pine flakes and un-treated southern pine flakes with PF resin.

Flake condition	Wood type	Contact angle (°)	
		Untreated southern pine	CCA-treated recycled southern pine
Air dry	Earlywood	72.52 (10.09)[a]	93.50 (13.37)
	Latewood	71.06 (10.23)	84.91 (10.39)
Oven dry	Earlywood	42.40 (7.24)	64.32 (21.34)
	Latewood	43.48 (6.58)	65.59 (23.53)

[a] Values in parentheses are standard deviations.

- <u>Hot water solubility</u>

The water-soluble materials in wood include inorganic salts, sugars, polysaccharides, cycloses and cyclitols, and some phenolics (Kuo *et al.* 2002). It has been reported in the literature that for southern pine, 2 - 3% extractives can be removed by hot water (Malds and Kamden 1999).

Both CCA-treated recycled wood and untreated southern pine were ground in a Wiley Mill to pass through a mesh screen of 20 microns. The particles were then sorted by using a shaker. Particles that passed through the 40 micron screen and were retained on a 60 micron screen of were collected for the test. Five specimen groups were thoroughly mixed according the same ratios of the five experimental flakeboard panels (Table 3). In addition, the same amount of PF resin (4.5%), oven dry weight basis, was added, while stirring. The resin was removed from a refrigerator and warmed to room temperature (70°F (21°C)) before tests. The specimens were placed in an oven with a temperature of 266 ± 4°F (130 ± 2°C) for 20 minutes to cure resin. Next, specimens were reground and resorted to get particle sizes between 40 - 60 microns. In accordance with ASTM D 1110 – 84, the hot water solubility of each group was determined. The untreated wood meal and CCA-treated wood meal were also tested as reference.

The hot water solubility were calculated as a percentage of weight loss to original specimen, as given in the equation below:

$$\text{Hot water solubility (\%)} = \frac{W_1 - W_2}{W_1} \times 100 \qquad [4]$$

Where, W_1 = weight of oven-dry specimen.

W_2 = weight of dried specimen after extraction with hot water.

The results of the hot water solubility are shown in Table 10, Group 1 had the highest value, and group 5 had the second highest value. CCA consists of water-soluble salts of CrO_3, CuO, and As_2O_5. However, these metallic ions are converted inside the wood into: copper/chrome and copper/chrome/arsenic compounds of very low water solubility (Raknes 1963). Differences of hot water solubility were not statistically significant.

Table 14. Hot water solubility of five group wood particles of CCA-treated recycled wood and untreated southern pine.

Group	Hot water solubility
1	6.17 (1.53)[a]
2	4.33 (1.26)
3	5.00 (0.50)
4	5.67 (0.58)
5	5.83 (1.61)
Untreated wood	5.00 (1.32)
CCA-treated wood	4.50 (0.50)

[a] Values in parentheses are standard deviations.

- <u>Gel time and viscosity</u>

Gel time measures time that is required to change a flowable liquid resin into a non-flowing gel. Resin gel time is considered a relative measure of the rate of resin cure. Since resin viscosity is indirectly related to other performance properties, it is desirable to be able to produce board resins within the range of about 100 to 500 centipoise at 70°F (21°C). Resin viscosity is very temperature sensitive. Therefore, the experimental resin was put in a water bath to obtain a constant temperature of 70°F / 21°C.

For this test, the specimens were made by wood particles blended with PF resin. One percent, three percent, six percent and nine percent of CCA-treated wood particles and untreated wood particles (same size of specimen as was used for hot-water solubility) based on resin weight were conducted, respectively. Wood particles and resin were mixed thoroughly. A Cole Parmer viscosity centipoise instrument (Model 98936-10) was used to measure viscosity. Also, the pH of each specimen was measured with a Lonalyzer digital pH meter (Model 601A), before the gel time measurement procedure. Gel time was measured with a Sunshine Gel Time Meter.

The viscosities consistently increased as the amount of wood particles for both CCA-treated wood and untreated wood material increased (Table 15). Since there was no reaction between PF and wood particles, the increasing viscosity indicated that the hygroscopic nature of wood absorbed the PF resin solvent, and then reduced the resin liquid. The viscosities of PF resin blended with untreated

wood particles were found to be consistently greater than that with CCA-treated -- wood particles (Figure 29). This result indicates the relatively lower hygroscopicity of the CCA-treated wood material. This difference could cause various spraying quality of PF blending.

Table 15 indicates that there was little variance of pH of PF resin and a combination of PF and wood particles. Vick (1991) reported that ions of chromium (Cr^{+3}) and copper (Cu^{+2}) in treated wood produced an accelerating effect of curing time. This study found that the gel time shortened as a result of the percent of CCA-treated wood particles increased. Conversely, gel time also shortened with increased untreated wood particles (Figure 30).

Typically, softwood is in the pH range of 4.0 – 5.9, with inconsistent differences between sapwood and heartwood (Lee *et al.* 2001). The process of water soaking used to prepare wood for flaking and drying the flakes to a suitable moisture content for flakeboard production will likely change the pH and buffer capacities of wood because of the removal of water-soluble extractives. The pH of wood may change the pH of the adhesive at the interface and thus modify the resin cure during hot-pressing (Maloney 1986).

Table 15. Summary of gel time, viscosity, and pH of PF resin mixed with CCA-treated wood particles and untreated wood particles at 1%, 3%, 6% and 9% weight.

Specimen		pH	Viscosity (Centipoise)	Gel time (min.)
PF		11.78	400	15.4
CCA-treated wood meal + PF	1%	11.78	475	15.7
	3%	11.72	665	15.0
	6%	11.67	1005	13.8
	9%	11.57	1735	13.4
Untreated wood meal + PF	1%	11.76	570	15.7
	3%	11.71	750	14.4
	6%	11.67	1180	14.3
	9%	11.61	2075	13.4

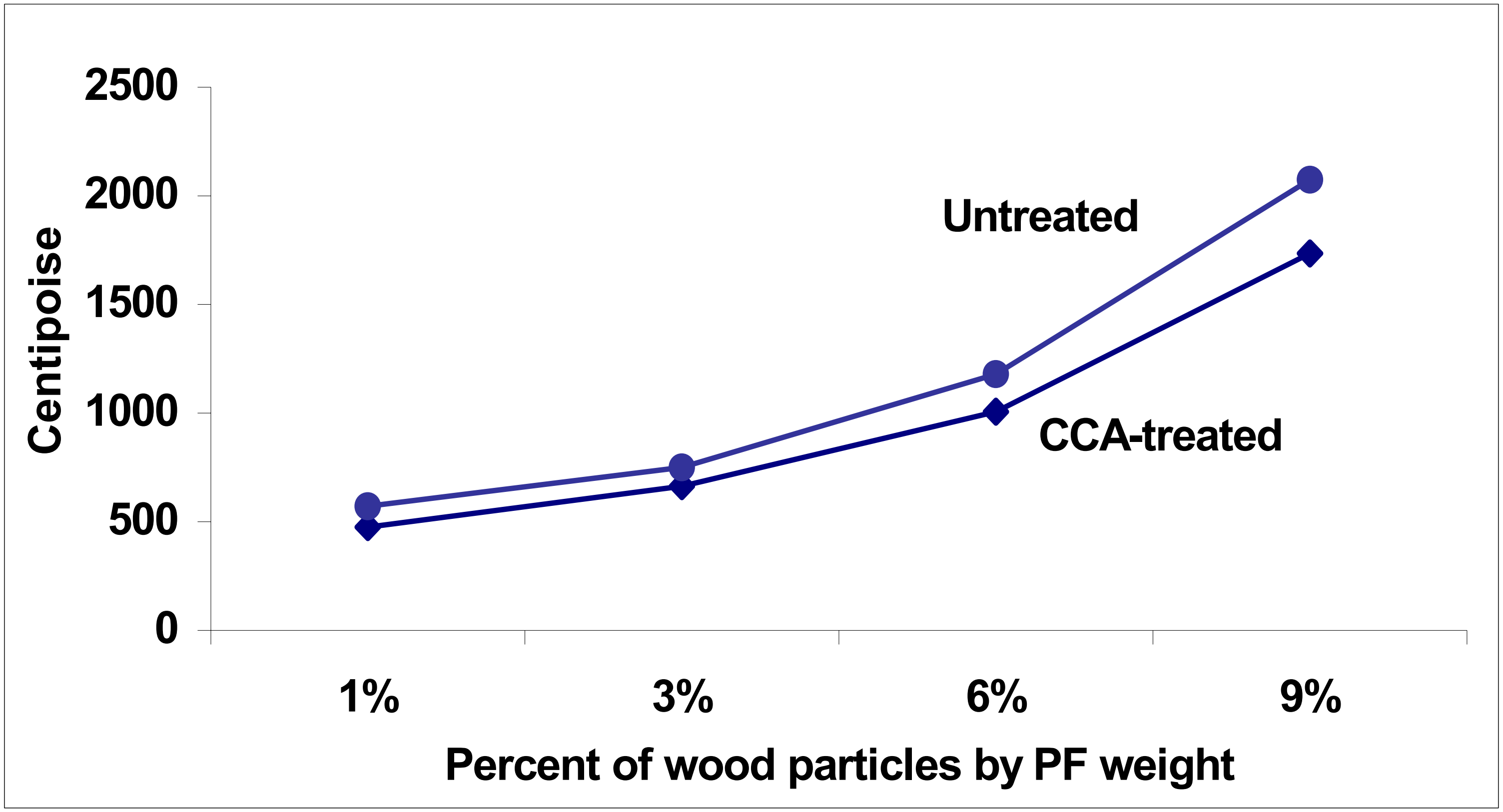


Figure 29. Viscosities of PF blended with either CCA-treated or untreated wood particles.

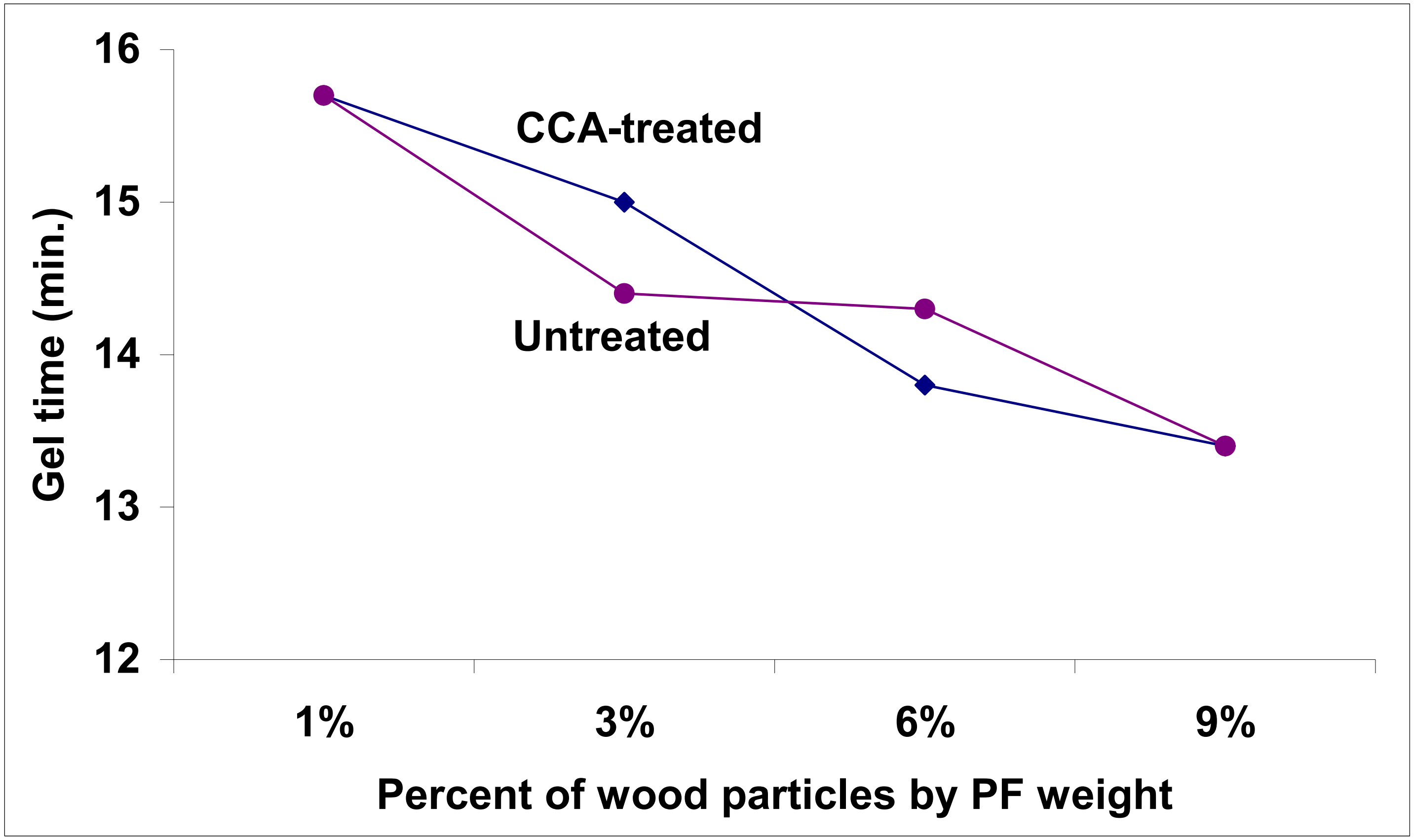


Figure 30. Gel time of PF blended with either CCA-treated or untreated wood particles.

CHAPTER 5. SUMMARY AND CONCLUSION

It is clear that flakeboard made from recycled CCA-treated wood is technically feasible. As expected, most mechanical and physical properties improved as the percent of recycled treated wood in the furnish decreased. Decay resistance increased as the percent of recycled treated wood in the furnish increased. The intermediate ratios (50% : 50%) of recycled CCA-treated wood and virgin untreated wood did not substantially reduce the physical and mechanical properties of the panels, and did improve decay resistance.

A great deal of variance proportion of testing specimens taken from experimental panels revealed that unbalanced properties are distributed in each experimental panel. More replicate panels and/or bigger dimension of individual experimental panels are suggested for future experiments in order to minimize experimental error.

LITERATURE CITED

1. APA Standard. PRP-108 Performance Standards and Policies for Structural-us Panels. APA - The Engineered Wood Association. 1997. APA Test Method P-1: Linear Expansion and Thickness Swell Measured from Oven Dry to Vacuum-Pressure-Soak.

2. American National Standard. ANSI A208.1-1998. Particleboard. National Particleboard Association.

3. American Society for Testing Materials. 1998. Standard test methods for evaluating properties of wood-based fiber and particle panel materials. D 1037-93. *In:* ASTM Annual Book of Standards. Vol. 4.10 Wood. ASTM, Easton, MD. pp. 150-179.

4. American Wood-Preservers' Association. 2000 Book of Standards. AWPA, P.O. Box 286, Woodstock, MD.

5. Behr, E.A. 1972. Decay and termite resistance of medium-density fiberboards made from wood residue. Forest Prod. J. 22(12): 48-51.

6. Boggio, K., and R. Gertjejansen. 1982. Influence of ACA and CCA waterborne preservatives on the properties of aspen waferboard. Forest Prod. J. 32(3): 22-26

7. Choong, E.T., and A. Attarzedah. 1970. Gluability of non-pressure treated southern pine veneer. Louisiana State Univ. Wood Utilization Notes. Agri. Expt. Sta. Release No. 18.

8. Clausen, C.A., S.N. Kartal, and J. Muehl, 2001. Particleboard made from remediated CCA-treated wood: evaluation of panel properties. Forest Prod. J. 51(7/8): 61-64.

9. Cooper, P.A. 1993a. Disposal of treated wood removed from service: the issues. *In:* Environmental Considerations in the use of Pressure-Treated Wood Products, May 13, 1993, Richmond, Va. pp. 85-90.

10. Cooper, P.A. 1993b. Leaching of CCA: is it a problem? Disposal of treated wood removed from service: the issues. *In:* Environmental Considerations in the Manufacture, Use, and Disposal of Preservative-Treated Wood. Proc. 7323. Forest Prod. Soc., Madision, Wis. pp.45-57.

11. Cooper, P.A. 1994. Reuse and recycling of utility poles in highway applications. Proceedings of CITW Life Cycle Workshop, June 20-21, 1994, Toronto, Ontario.

12. Cooper, P.A. 1996. Management of used poles removed from service. Second Southeast Pole Conference, Jan. 22-25, Mississippi State University and Forest Product Lab. Proceeding #7287, pp.102-112.

13. Cooper, P.A., T. Ung, J.P. Aucoin and C. Timusk. 1996. The potential for reuse of preservative treated utility poles removed from service. Waste Management & Research. 14:263-279.

14. Cooper, P.A. 1999. Future of wood preservation in Canada – disposal Issues. 20th Annual Canadian Wood Preservation Association Conference, Oct. 25-26, 1999, Vancouver BC.

15. Deppe, H.J. 1970. The protection of sheet materials against water and decay. J. Inst. Wood Science 5(3): 41-45.

16. Felton, C.C. and R.C. DeGroot. 1996. The recycling potential of preservative-treated wood. Forest Prod. J. 46(7/8): 37-46.

17. Hall, H., R. Certjejansen, E. Schmidt, C. Carll, and R. De Groot. 1982. Preservative treatment effects on mechanical and thickness swelling properties of aspen waferboard. Forest Prod. J. 32(11/12): 19-26.

18. Hartford, W. H. 1986. The practical chemistry of CCA in service. Proc. Annual meeting of the American Wood Preservers' Assoc. 82:28-43. AWPA, Stevensville, Md.

19. Hutchinson, C.I., S.L. Choong, and J.M. Mclaughling. 1977. Bonding of radiata pine veneers treated with CCA preservatives by the momentary immersion method. New Zealand J. of Forestry Sci. 7(1): 113-122.

20. Jeihooni, A., R.L. Krahmer and J.J. Morrell. 1994. Properties and decay resistance of preservative-treated douglas-fir flakeboard. Wood and Fiber. 26(2), 1994, pp. 178-184.

21. Kazi, K.M. Feroz and P.A. Cooper. 1999. Recovery and reuse of chromated copper arsenate (CCA) wood preservative from CCA treated wastes. 20th Annual Canadian Wood Preservation Association Conference, Oct. 25-26, 1999. Vancouver BC.

22. Kuo, L., J. Jen, M. Lee and W. Hwang. 2002. A microwave-assisted extraction method for determining hot water solubility of wood. Wood and Fiber Sci. 34(1): 72-76.

23. Lea, R.G. and R.W. Berry. 1995. Evaluating the resistance of wood-based panel products to fungal attack. IRG/WP 95-20071. Inter Res. Group on Wood Preservation, Stockholm, Sweden. 9 pp.

24. Lebow, S. 1996. Leaching of wood preservative components and their mobility in the environment – summary of pertinent literature. Gen. Tech. Rep. FPL-GRT-93. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Product Laboratory. 36 p.

25. Lebow, S. and L. Gjovik. 2000. Properties and durability of CCA treated flakeboard. American Wood Preservers' Assoc. 96th Annual Meeting, San Francisco, CA.

26. Lee, S., Q. Wu and B. Strickland 2001. The influence of flake chemical properties and zinc borate on gel time of phenolic resin for oriented strandboard. Wood and Fiber Sci. 33(3): 425-436.

27. Maldas, D. and D.P. Kamdem. 1999. Wettability of extracted southern pine. Forest Prod. J. 49(11/12): 91-93.

28. Maloney, T. M. 1986. Modern particleboard and dry-process fiberboard manufacturing. 2nd printing. Miller Freeman Publications. San Francisco, CA. 672 p.

29. Marx, B.D. 2001. Experimental Statistics 7015 Lecture Notes. Louisiana State University. Baton Rouge, LA.

30. Mendenhall, W., R.J. Beaver and B.M. Beaver. 1999. Introduction to probability and statistics. Brooks/Cole Pubilishing Company. Pacific Grove, CA.

31. Merrill, D.W., French, and R.L. Hossfeld. 1965. Wood fiberboard studies. Part II. Effects of common molds on physical and chemical properties of wodd fiberboard. Tappi 48(8): 47-474.

32. Micklewright, J. 1998. Wood preservation statistics 1997. American Wood-Preservers' Assoc., Washington, D.C.

33. Munson, J. and D.P. Kamdem. 1998. Reconstitute particleboard form CCA-treated red pine utility poles. Forest Prod. J. 48(3): 55-62.

34. National Particleboard Association. 1993. Particleboard. ANSI A208.1-1993. National Particleboard Assoc., Gaithersburg, MD.

35. Prasad, T., P. humphrey, and J. Morrell. 1994. The effects of chromated copper arsenate and ammoniacal cooper zinc arsenate on shear strength development of phenolic resin to Sitka spruce bonds. Wood and Fiber Sci. 26(2): 223-228.

36. Raknes, E. 1963. Gluing of wood pressure-treated with water borne preservatives and flame retardants. Journal of the Institute of Wood Science. 11(12): 24-44.

37. Ramsey, F.L. and D.W. Schafer. 2002. The statistical sleuth – a course in methods of data analysis. Second Edition. Duxbury, Pacifi Grove, CA. 742 p.

38. Roliadi, H., C.Y. Hse, E.T. Choong and T.F. Shupe. 2000a. Gluability of out-of-service utility poles. Forest Prod. J. 50(10): 76-81.

39. Roliadi, H., C.Y. Hse, E.T. Choong and T.F. Shupe. 2000b. Decay resistance of out-of-service utility poles as related to the distribution of residual creosote content. Forest Prod. J. 50(11/12): 64-68.

40. SAS 8.e. 2000. SAS Institute Inc. SAS Campus Drive, Cary NC 27513.

41. Schmidt, E.L. 1987. Decay and strength reduction in aspen waferboard. *In*: IUFRO symposium on the Protection of Wood-based Composite Products. Honey Harbour, Ontario, Canada, May 16, 1987.

42. Schmidt, E.L., D.W. French, R.O. Gertjejansen, J. Hermann and H.J. Hall. 1978. Strength reductions in particleboard caused by fungi. Forest Prod. J. 28(2): 26-31.

43. Schmidt, E.L., H.J. Hall, R.O. Gertjejansen, C.G. Carll and R.C. DeGroot. 1983. Biodeterioration and strength reductions in preservative treated aspen waferboard. Forest Prod. J. 33(11/12): 45-53.

44. Smith, R.L. and R. Shiau. 1998. An industry evaluation of the reuse, recycling, and reduction of spent CCA wood products. Forest Prod. J. 48(2): 44-48.

45. Thompson, W.S. 1962. Effect of preservative salts on the gluing of treated sweetgum veneer. Forest Prod. J. 12(9): 431-436.

46. Toole, E.R. and Barnes, H.M. 1974. Biodeterioration of particleboard. Forest Prod. J. 24(10): 55-57.

47. Vick, C.B. 1980. Structural bonding of CCA-treated wood for foundation systems. Forest Prod. J. 30(9): 25-32.

48. Vick, C.B. 1991. Preliminary findings on adhesive bonding of CCA-treated southern pine. Proceedings from the Adhesives and Bonded Wood Symposium. pp 158-176. November 19-21, 1991. Seattle, WA.

49. Vick, C.B. 1997. Enhanced adhesion of melamine-urea and melamine adhesives to CCA-treated southern pine lumber. Forest Prod. J. 47(7/8): 83-87.

50. Vick, C.B., and A.W. Christiansen. 1993. Cure of phenol-formaldehyde adhesive in the presence of CCA-treated wood by differential scanning calorimetry. Wood and Fiber Sci. 25(1): 77-86.

51. Vick, C.B., R.L. Geimer and J.E. Jr. Wood. 1996. Flakeboards from recycled CCA treated southern pine lumber. Forest Prod. J. 46(11/12): 89-91.

52. Vick, C.B., and T.A. Kuster. 1992. Mechanical interlocking of adhesive bonds to CCA-treated southern pine – a scanning electron microscopic study. Wood and Fiber Sci. 24(1): 36-46.

53. Winandy, J.E. 1995. Effects of waterborne preservative treatment on mechanical properties: a review. Proc. Annual meeting of the American Wood Preservers' Assoc. 91:17-33. AWPA, Woodstock, MD.

54. Zhu, S.-S., D. Tomberlin, and J. Buogniorno. 1998. Global forest products consumption, production, trade and prices: Global Forest Products Model projections to 2010. Global Forest Products Outlook Study Working Paper Series GFPOS/WP/01. FAO, Forestry Policy and Planning Division, Rome. 333p.

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