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RECONSTITUTED PARTICLEBOARD FROM CCA TREATED RED PINE

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RECONSTITUTED PARTICLEBOARDS FROM CCA TREATED RED PINE

By

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ABSTRACT

RECONSTITUTED PARTICLEBOARDS FROM CCA TREATED RED PINE

By

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Large quantities of pressure treated wood will be coming out of service in the near future. An attempt to alleviate the amount going to landfill was the focus of this thesis.

Two studies on the recycling of CCA (chromated copper arsenate) treated wood into wood composites were completed. The first objective was to determine the feasibility and proper amounts of resin to manufacture recycled composites. The second objective was to evaluate the effects of the treated wood proportion in the composite on physical and mechanical properties.

Results from the first study showed that 4 and 8 percent solids were suitable quantities of resin to manufacture wood composites from CCA treated wood, and there was no significant biological decay when using CCA treated wood in the boards. From the second study, it was found that using up to 50 percent treated wood did not significantly reduce the board physical and mechanical properties.

Overall, the objectives of the studies were met, and it was feasible to manufacture particleboards utilizing CCA treated wood.

To my late grandfather, Paul C. Munson.

ACKNOWLEDGMENTS

A publication such as this would not be possible without the assistance of my major professor, Dr. Pascal Kamdem. His patience and understanding while I learned about wood composites and preservation have been invaluable. Hopefully some day I will be as professional, ethical, and scientific as he. Dr. Kamdem has not only been a great mentor, but a friend with which I could personally talk to. This relationship is one that will last a lifetime.

I would also like to thank Miss Renee Essenmacher for her help during pressing and evaluation of the particleboards. This thesis would have been much more difficult to produce in the time allotted without her help.

Also, gratitude goes to Georgia-Pacific and Weyerhaueser Corporations for donating the resins used, Hydrolake Leasing Company for the red pine utility poles, and Universal Forest Products for use of their equipment.

Finally, I would like to thank my wife, Heidi Munson. Heidi has given me the insight, determination, and courage to make this thesis possible. She has been absolutely terrific through both the good times and the tough.

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INTRODUCTION

This thesis sets forth a series of studies on the feasibility to produce wood composites from CCA treated wood. The first study is done to determine the proper quantities and what types of adhesives would be suitable to use with CCA treated wood. The second study uses those resins and resin contents to determine the effect of CCA treated wood proportions in the particleboards on their mechanical and physical properties.

CHAPTER 1

RATIONALE AND SIGNIFICANCE

Problem Analysis

Study Topic

The topic of this study is to determine if particleboards can be made from preservative treated, red pine utility poles. It is an important topic to reduce the amount of CCA treated wood that goes to land fill each year, and to develop another option for particleboard furnish. "Furnish" is defined as the material used to produce particleboard. Research on this topic will advance the field by providing a method from which others can follow to perfect a product, as well as reduce environmental distress.

The research problem area consists of wood preservation, particleboard production, new forest products, wood science, recycling, and environmental contamination.

Due to the increased awareness of large quantities of pressure treated wood coming out of service, scientists have started to develop methods of reconstituting pressure treated wood into useful products. In 1995, approximately 579 million cubic feet of preservative treated wood was produced, of which 424 million cubic feet (73 percent) was treated with chromated copper arsenate (CCA) (American Wood Preservers'

Institute, 1996). Looking back on the use of waterborne preservatives, almost a half-billion cubic feet have been produced yearly since the late 1970s. In 1993 it was estimated that over 353 thousand cubic feet of treated wood were removed from service (Cooper, 1993).

Wood products for outdoor uses such as decking, shingles, railroad ties, utility poles, and fence posts are treated with preservatives in order to extend the service life. A preservative is a chemical compound that is toxic to humans and microorganisms and hazardous to the environment. The most commonly used wood preservatives are chromated copper arsenate (CCA), ammoniacal copper zinc arsenate (ACZA), creosote, and pentachlorophenol (Lehmann, 1969). Waterborne CCA is generally used for the treatment of structural materials and utility poles. Creosote, a tar-oil type preservative, and pentachlorophenol are used in railroad ties, timber bridges, and utility poles. Today, there is a trend toward replacing creosote and pentachlorophenol with CCA because of their high toxicity(Cooper, 1993).

It is estimated that the service life of CCA treated utility poles and crossties is approximately 25 years, depending on the geographical location. After 20 years, utility poles and crossties are usually removed from service. Treated lumber from construction and demolition sites and cut-offs from treated utility poles and posts also generate treated wood waste. Therefore, significantly greater volumes of treated wood will be available due to the increased use of CCA.

The question now is what will we do with the large quantities of CCA treated wood coming out of service in the future? Currently there are four main ways to dispose of treated wood. The most popular option today is to landfill. If the projections of quantities coming out of service in the near future are correct and considering that wood is a high volume material, landfills will be overwhelmed. Landfill will become a very expensive alternative and may also produce environmental problems. In large quantities, treated wood may leach heavy metals into soils, streams, rivers, and groundwater. The cost (Stalker, 1993) and the current level of environmental awareness will reduce landfilling as an attractive option for disposal of treated wood waste (Cooper, 1994; Marer et al., 1992; Webb et al., 1994; Lehmann, 1969)).

Burning treated wood in controlled environment settings could be a viable option. Recent literature suggests that few to negligible air quality problems were encountered from burning treated wood at the right temperature and appropriate oxygen rate (Marer et al., 1992; Pasek, 1995). These results were obtained from laboratory experiments. Further pilot scale or industrial tests are needed to validate this option. Wood preservatives absorbed in the wood matrix can be recovered by incineration (Pasek, 1992; Pasek, 1995), biotechnology, or solvent extraction (Honda et al., 1991).

A third opportunity to dispose of treated wood would be to resaw larger poles, pilings, timbers, and posts into smaller dimension lumber that could be retreated for further protection (Felton et al., 1996). This option would greatly reduce the amount of treated wood going to landfill, but at the same time reduce the amount of decay resistance in the final product by removing the high-preservative exterior retention zones. This may also be a good source of raw material for laminated veneer lumber (LVL), gluelam, and parallam lumber if adhesive problems were overcome.

The feasibility of poles removed from service in Ontario and Québec for sawn products was investigated (Chow et al., 1984). Significant volumes of high quality roofing products were recovered. However, the reuse of poles and ties is dropping because of the cost of re-manufacturing and also because incipient decay reduces mechanical properties needed in sawn lumber.

A final attractive alternative for the discarding of treated wood would be to convert this high-quantity resource into wood composites. If properly managed, recycled treated wood can be a good source of fiber for engineered products such as hardboard, fiberboard, particleboard, oriented strand board (OSB), strandboard, or cement-bonded boards (Schmidt et al., 1994). Composites made from treated wood waste are also expected to have an extended service life.

Problem Statement

The problem that is the focus of this study is to reduce the amount of CCA treated wood that goes to landfill each year.

Research

This research will contribute to our understanding of how compatible CCA treated wood and urea and phenol formaldehyde resins are. Recent studies have shown a discrepancy that CCA treated wood was incompatible with these resins. Red pine (*Pinus Resinosa Ait.*) has not been used in any of these prior studies, and particleboard was not the target product.

This research will help us understand how the amount of treated fiber affect the physical properties (such as bending strength and internal bonding strength) of the particleboard. This can be examined by using five ratios of treated to untreated wood fiber and examining the physical properties.

Besides physical properties already stated, the thickness swelling and water absorption of the treated particleboard may be less than that of untreated particleboard. This would benefit the flooring areas around toilets and sinks by making the floor more water resistant. Water is the main way that fungi travel from place to place and break down the main components of wood fiber. By using the phenol formaldehyde resin, which is water resistant, and a treated wood fiber would create a decay resistant product. This could be proven by the use of an accelerated decay test, where the main types of fungi are grown with the particleboard as a food source. The particleboard is weighed before and after inoculation with fungi to determine the weight loss, or the amount the fungi consumed. This would help us to learn more about the threshold of CCA concentration needed to stop decay.

Creating such a product would benefit many user groups. The wood preserving industry would benefit from such a product by the extension of service life of a treated product, thus alleviating pressure to find ways to dispose their product. Particleboard producers would gain an inexpensive, new furnish that would reduce the costs of harvesting trees and the environmental stresses of over-harvesting. In the same time, less trees will be harvested and less landfill needed considering that 40 percent of landfill volume is occupied by wood products. A decay-resistant composite product could be used for flooring around sinks, toilets, and showers, as well as manufactured housing and trailer homes. On a global level, Earth would ecologically benefit by decreasing the heavy metal leaching in high quantities of treated wood around landfills. A reconstituted board would reduce this problem drastically.

Hypotheses and Assumptions

Assumptions made while conducting this research include: 1. Red pine will have the same characteristics as southern yellow pines (*Pinus spp.*) or ponderosa pine (*Pinus ponderosa*). Other studies were done on southern yellow and ponderosa and showed they may not behave the same way. 2. It will be feasible that the particles of treated red pine and untreated red pine will be mixed together in different ratios and still make a standard particleboard. Hopefully no incompatibility between furnishes will be present. 3. It is also assumed that the treated poles that will be ground will produce a consistent amount of CCA oxides. It is most likely that each pole will be treated a little differently, but after grinding, the amount of CCA present in the fiber will be almost homogeneous throughout.

Literature Review

Recycling treated wood into composites is not a new concept but very little data about the feasibility and properties of the final product are available in the literature.

There has been no actual research done on particleboards made with recycled furnish. Also, little has been done on red pine or CCA treated red pine. At this time, recycling of forest products has not received the attention that it should. The only research that has been conducted on making particleboards is based on an objective of creating a deterioration free product with virgin materials. For example, freshly cut aspen (*Populus tremuloides*) was ground into chips, and then the chips were treated and then pressed into particleboards (Boggio et. al, 1982). Two types of phenolic resins were used and physical properties of the boards were compared. All of the resin-preservative combinations exceeded minimum standards set by the American National Standards Institute (ANSI, 1993) for modulus of rupture and modulus of elasticity (MOR and MOE) and for internal bond (IB). When compared to untreated control samples, the CCA treated waferboards produced lower strength properties. This study confirmed that CCA definitely reduces mechanical properties, but not to the extent of jeopardizing the grade of particleboard.

Hall confirmed this with treated aspen wafers in 1982, except he found that the MOR dropped by 59% when using CCA treated wood as a furnish. The method of treatment was different. In this case the wafers were treated with CCA at the same time of spraying with resin, compared to Boggio's industrial treatment before resin application. A positive aspect of Hall's work was that the amount of irreversible thickness swell difference between treated and untreated was under 1%.

A third paper (Schmidt et al., 1983) showed that when boards were made with aspen wafers and then preservative treated with CCA, there was no loss of strength after accelerated aging. This backs Boggio's findings that there was little loss in strength, but was the converse of what Hall found. There were findings that were argumentative between these three authors. The main question between them was, "is CCA affecting the bonding between wood and resin?"

To answer this question many studies were done by one scientist (Vick, 1990). Vick used electron microscopy to evaluate a compatibility problem between CCA and PF resin. He found that the chemistry of the broken wood surface was mostly made up of lignocellulose, a primary bonding site for PF resin. This surface had been oxidized with the CCA chemical, causing the lignocellulose to be covered and weakened. He thought that this was the main reason why there was so much difficulty getting consistent results.

Several other studies have suggested that mechanical properties of wood based composites made from CCA treated particles were lower than those of virgin particles

(Gertjejansen et al., 1988; Vick, 1980; Vick et al., 1990; Vick et al., 1996). The reduction in properties was attributed to the surface modification by the preservative treatment or the interaction between preservatives and resin. All of these studies reporting reduction of mechanical properties involved methods of first reducing the virgin wood to particles and then treating the particles with preservatives. The treatment, of course, creates chemical modification on the surface of the particles which is the interface between particles and resin during gluing and pressing. The reduction of already treated wood into particles and reassembling into new forms using adhesives has been done and has shown positive results.

Research on CCA treated composite production feasibility began again. It was found that preservative treatment with CCA was not detrimental to adhesive bonding for different wood species, and even a higher glue line shear strength was reported by Janowiak in 1992. This means CCA treated wood would be stronger in veneering applications.

Strength was reported higher again in CCA treated flakeboards by Kumar in 1993. He found that chemical modification of flakes prior to gluing and pressing into boards represent a simple, inexpensive method for improving dimensional stability and decay resistance in CCA treated particleboard. Aspen wafers created boards that showed a reduced thickness swell by 25-30% with CCA treatment. It also increased MOR by 40% but did not affect the IB. This would mean that CCA treated aspen, ground and then glued would be not only feasible, but profitable.

At the same time, a study showed the feasibility of recycling treated hardwoods into particleboards with UF and PF resin (Suzuki, 1993). He found by doing an exterior durability test, that the PF - CCA treated hardwoods were durable to last 6 years in the elements.

One other study was done on reconstitution by using previously treated lumber (Vick et al., 1996). Vick showed that flakeboards made of ring-cut flakes from recycled CCA treated southern yellow pine (*Pinus* spp.) lumber and bonded with liquid PF resin had property values substantially lower than those of untreated. These findings were based upon flakes of variable size and shape, which caused a difference between untreated and CCA treated flakes. The particle geometry is known to influence the bending strength properties of the final product. Our project consists of grinding CCA treated utility poles into uniform particles and used as raw material for medium density particleboards.

Overall Objectives

The objective of the first study was to investigate the feasibility of producing particleboards from CCA treated utility poles using both urea and phenol formaldehyde as the binders. Then, boards would be made and physical and mechanical properties would be evaluated.

The objective of the second study was to investigate the effect of increasing the CCA treated wood proportion in particleboards on some mechanical and physical properties. Special care was taken to ensure particle size was the same for both virgin and treated particles. Based on the first study's findings, the optimal resin type and content were used, boards produced, and properties evaluated.

CHAPTER 2

STUDY I: FEASIBILITY AND RESIN CONTENT DETERMINATION

Objective

This study had two objectives. The first objective was to investigate the feasibility of producing particleboards from CCA treated utility poles using urea and phenol formaldehyde resins as bonding agents. The second objective was to evaluate physical and mechanical properties of those boards.

Materials and Methods

Materials

Untreated and CCA treated red pine *(Pinus resinosa Ait.)* poles were obtained from Hydrolake Leasing Service in McBain, Michigan. All poles were kiln-dried to 30 percent moisture content (MC) prior to treatment. Half the poles were then pressure treated with a 2 percent total oxide solution of CCA-C for 6 hours with a modified full-cell method. The treatment included an hour of initial vacuum at 91 kPa (27 inches) of mercury followed by 4 hours of pressure at 1.03 MPa (150 psi), and a final vacuum of 1 hour. The target retention of total oxides in the poles was 9.6 kg/m^3(0.60 pcf). The treated poles were then air-dried to 19 percent MC.

Particle Manufacture Methods

Poles were chipped with an Morbark Eager Beaver Chipper, and chips reduced into particles with a laboratory hammermill. Particles from untreated red pine were named virgin furnish and particles from CCA treated red pine named treated furnish.

Attention was paid to particle size to avoid an imbalance which could create panel warping and strength reduction. Particles were sifted by size with a vibrating inclined screen, and only particles passing through 10 but held by 16 mesh screens were selected for particleboard production. A screen analysis was performed on a sample of both particle types with an electric shaker for 5 minutes using screen 8, 10, 16, and 30 mesh. The thickness, width, and length of 1000 screened particles were also measured by light microscope. Screened particles were air dried to 5 ± 2 percent MC and used to manufacture particleboards.

The pH of both furnishes was determined with a pH meter. In a beaker, 10 g of screened particles were mixed in 100 ml of distilled water for 30 minutes using a sonicated bath and the pH determined.

Composite Manufacture Methods

Commercial liquid urea formaldehyde resin (UFR) and phenol formaldehyde resin (PFR) provided by Georgia Pacific, each containing around 50 ± 1 percent solids, were used in this study. Screened and dried particles were sprayed with 2.5, 4, and 6 percent resin solids content based on oven-dry weight of the furnish. A sample board calculation is shown in Appendix A.

Several studies reported reduced mechanical properties of wood composites made of CCA treated wood (Vicks, 1990; Boggio and Gertjejansen, 1982) due to the interference of the preservatives with the adhesion of hot or cold press adhesives. The weak adhesion is also explained by the reduction of active hydroxyl or carboxylic groups on the wood surface. The pH, surface energy, and surface tension of wood modified after preservative treatment may also contribute to the weak adhesion of treated wood. Several options have been proposed to improve adhesion of CCA treated wood. The most promising alternatives are: the improvement of adhesive formulation to increase the mechanical interlocking by a deep penetration of adhesive in wood (Vick, 1990), the treatment of wood with a surface modifier such as sodium hydroxide (Vick, 1980) which increases wood surface reactivity with adhesives, or the use of a relatively high amount of resin (Moslemi, 1974). Different amounts of resin were used to produce boards in order to evaluate their effect on the properties of reconstituted boards.

Particles were sprayed with resin in a laboratory rotary drum blender for 5 minutes and mats were hand-formed in a 40.6 cm square (16" square) frame. The MC of the particles in the mat before pressing was 8 ± 2 percent. A Berthelsen thermo-oil heated hydraulic press was used to press the mat between two steel platens to a nominal thickness of 10 mm (0.375"). The time interval from the application of resin to pressing was kept constant at 5 minutes in all trials. The press time was 6 minutes, the pressure 800 psi (8.28 MPa), the press temperature 190°C (325°F), and the closing time 13 seconds.

Low density areas on each board were removed by trimming one inch on all edges. Trimmed boards were kept at 65 percent relative humidity (RH) and 20°C (68°F) for at least 40 days before testing or until they reached their equilibrium moisture content

(EMC). The EMC and density of boards were 5±1 percent and 750±50 kg/m^3(47±3 pcf), respectively.

Boards with untreated and CCA treated red pine were manufactured containing 2.5, 4, or 6 percent by weight UFR or PFR. Ten boards of each type were made, for a total of 120 boards. The manufacture sequence of boards was designed such that all the replicates of each type were made consecutively, due to some problems associated with the cleaning of the rotary drum blender.

Material Testing Methods

Samples were cut from each board to conform with American Society for Testing Materials (ASTM) Standard number D1037-95 guidelines to obtain: 2 specimens for bending, 3 for thickness swelling (TS) and water absorption (WA), 6 for internal bond (IB), and five 2.5 by 2.5 cm (1" x 1") strips for soil block (See Figure 1). Samples were stored in a room conditioned at 65 ± 1 percent RH and temperature of 20 ± 3° C (68 ± 6° F) until tested. ASTM Standard 1037-95 tests for static bending and IB were all conducted using an Instron testing machine. TS and WA were conducted by ASTM Standard 1037 as well.

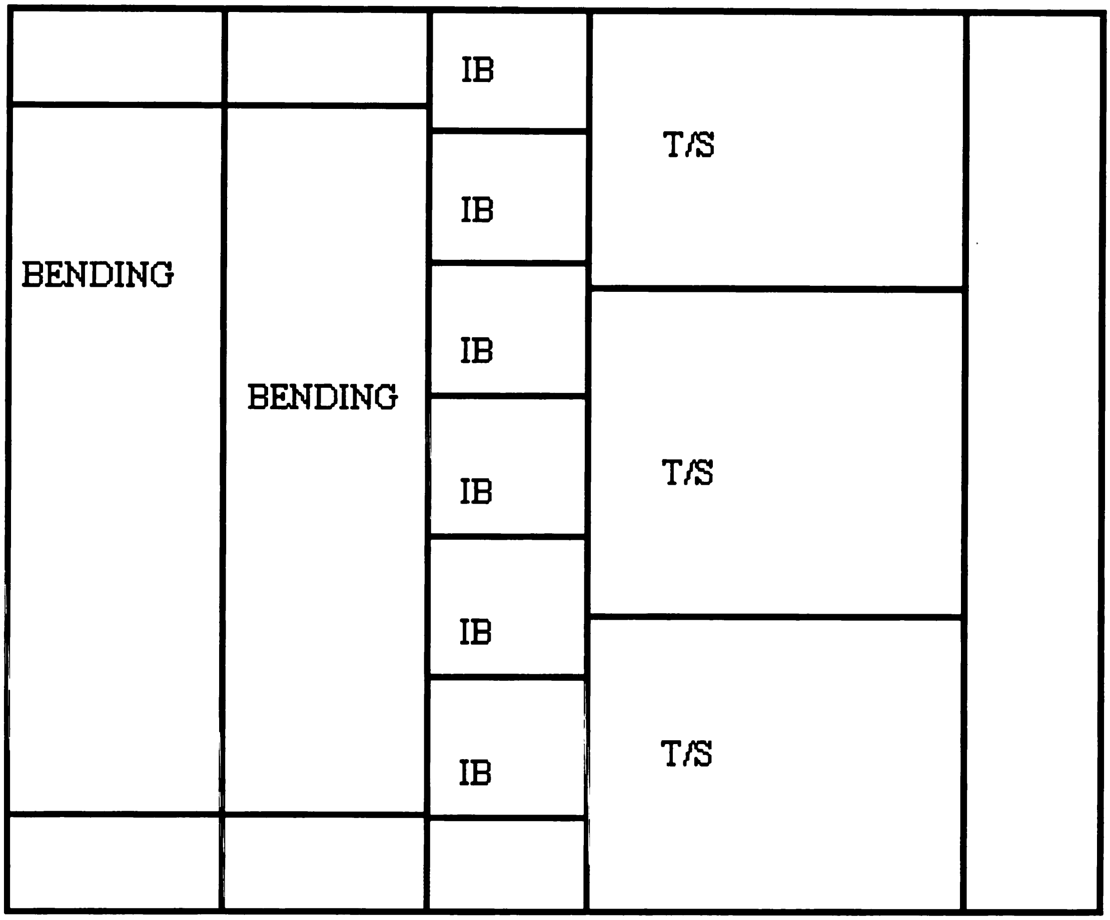

Figure 1 - Sample particleboard cutting pattern

Chemical Analysis and Water Leaching

Three samples measuring 10.2 by 10.2 by 1 cm (4" x 4" x 0.375") with a combined surface area of 720 cm^2 (111 in^2) and a total of 200 g (0.45 lb) oven dry weight were completely immersed in 500 ml distilled water for one month. About 15 ml of water was sampled every 48 hours and analyzed for copper, chromium and arsenic content using atomic absorption spectroscopy (AAS). Leached and unleached solid samples were acid digested and their metal content determined. The detection limit of the AAS used was less than 100 ppb for copper and chromium, and about 10 ppm for arsenic

(AWPA, 1996). All samples with less than 10 ppm arsenic were spiked with a 20 ppm known standard, this allows us to measure 1 ppm arsenic concentration.

Biological Performance

A modified AWPA protocol (E10-91) laboratory soil block test was conducted described below (Kamdem, 1995). Brown fungi *Gloeophylleum trabeum* (Pers. Ex Fr.) Murr.(Madison 617 ATCC 11539) and *Poria placenta* (Fr.) Cooke(Madison 698, ATCC 11538), and white rot fungi *Trametes versicolor* (L. Ex FR.) Pilat (R-105), *Irpex lacteus* Fries (FP-105915), and *Pleurotus ostreatus*(Jacq. Ex Fr.) Kummer(ATCC 32237) were used. Specimens used for the bioefficacy measured 2.5 by 2.5 by 1 cm (1" x 1" x 0.375"). Culture boxes were incubated until the aspen feeder strip was covered by fungus. Specimens were placed on the fungus covered feeder strip and kept for 16 weeks at 90 percent RH and 25°C (77° F). After 16 weeks, specimens were removed from culture boxes, scraped clean to remove superficial mycelium and reconditioned at 65 percent RH and 20°C (68° F) until they reach their EMC and their weight stabilized. Weight loss after exposure to pure culture of a test fungus was used as the index of decay.

Results and Discussion

Particle Size Analysis

Particle length, width, and size distribution are summarized in Figures 2,3, and 4, respectively. About 80 ± 5 percent of the thousand particles analyzed by light microscopy had an average length of 3.6 ± 1.0 mm (0.14 ± 0.04") and an average width of 1.5 ± 0.3 mm (0.06 ± 0.01"). The average slenderness ratio was 2.64: 1, which is defined as the ratio of length to the diameter of the particle. From the Tyler sieve analysis, Figure 4 depicts particle size ranged from 0.5 to 2.3 mm (0.02 to 0.09"). This shows the same distribution for both treated and untreated furnish by weight. Eighty-seven percent of all particles were between 1.52 and 1.78 cm (0.06 and 0.07") in size. This data is in agreement with microscopy measurements based on distribution and standard deviation. Any differences between microscopy and Tyler sieve data could be explained by the many angles at which particles could pass through the Tyler sieves (0 - 180 degrees).

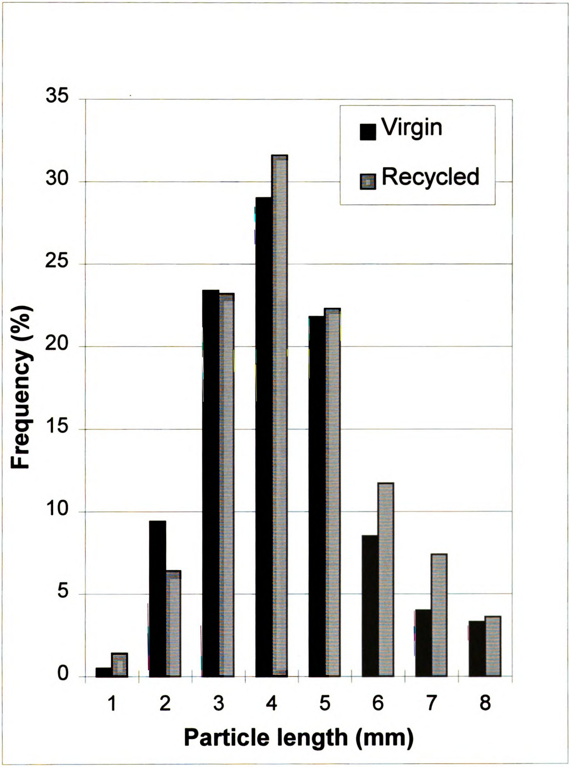

Figure 2 - Particle length distribution

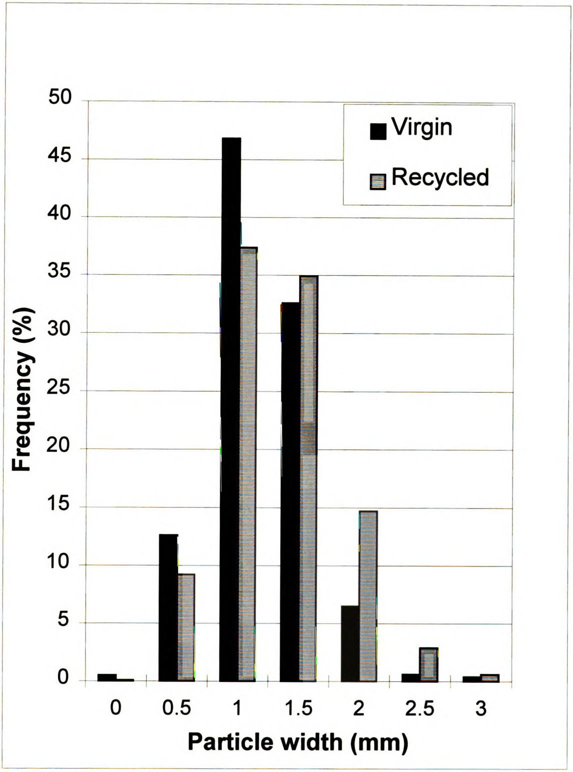

Figure 3 - Particle width distribution

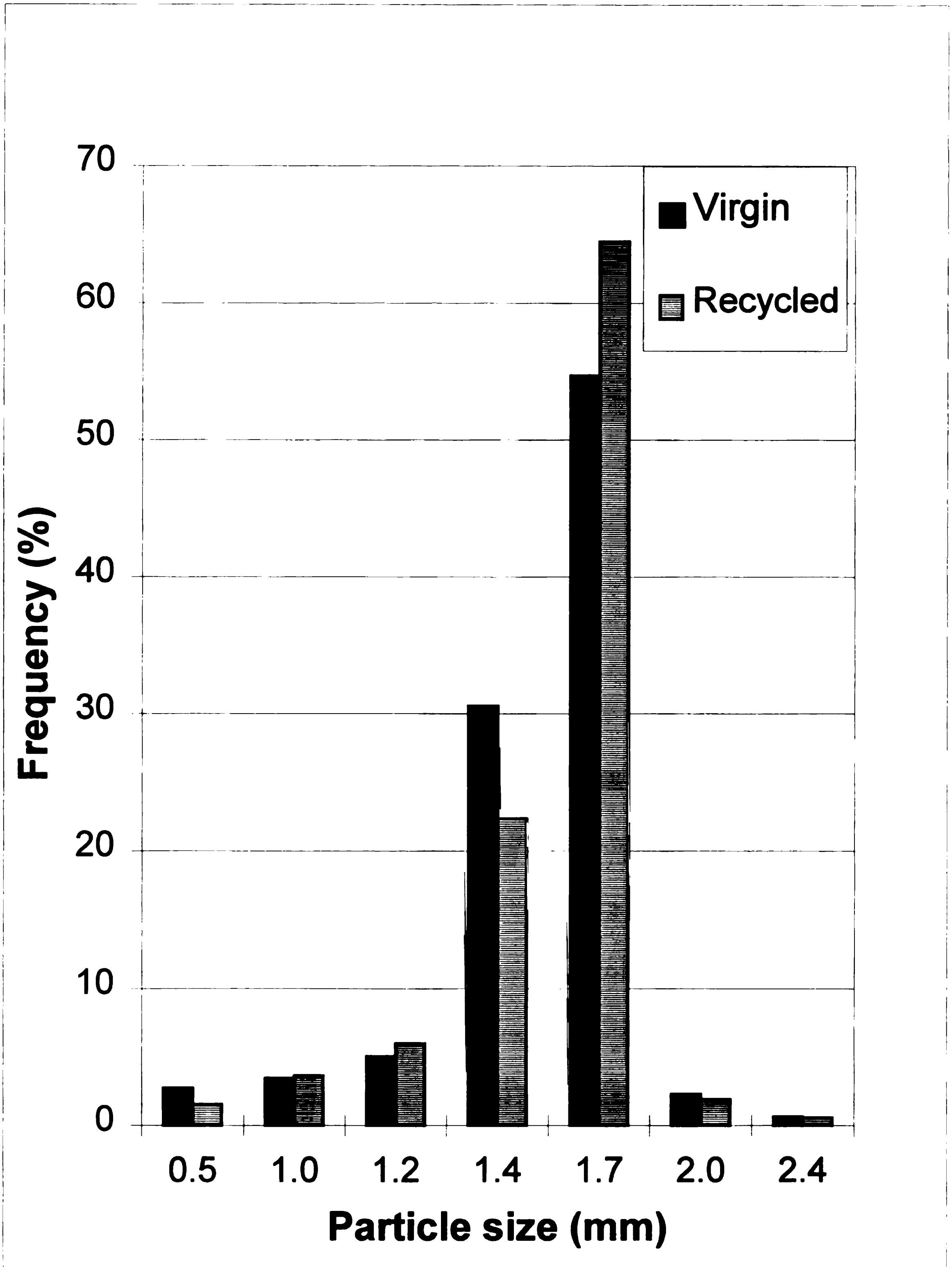

Figure 4 - Particle size class distribution via Tyler sieves

Particle pH

The particle pH was found to be slightly different for virgin versus treated particles. Virgin particles had a pH of 4.9 compared to 5.1 for the CCA-treated furnish. However, pH obtained through this method is not representative of the pH of the wood surface since the pH meter evaluates the concentration of H^+ liberated in the water medium. Therefore the pH could be influenced by the solvent. Thomason and Pasek have shown that pH of southern yellow pine tested in water is different than tested in acetone (17). Knowing the low pH of CCA (pH $\cong$ 2), the similarity in pH of CCA treated and virgin red pine suggest that wood may behave as a buffer, or the retention of CCA in the wood analyzed was low.

Chemical Analysis and Water Leaching

The chemical retention in the particles from utility poles before and after board manufacturing are listed in Table 1. Data in Table 1 indicate a negligible or undetectable loss of copper, chromium, or arsenic during the board manufacture processing. The total oxide retention of particles from treated poles was 7.95 kg/m^3 (0.50 pcf). The retention was lower than the target retention of CCA treated red pine poles (0.60 pcf) but higher than the retention of ground contact commodities (0.40 pcf). A statistical analysis showed no significant difference at the 5% level between the chemical content of particles before and after the particleboard fabrication. Depletion of copper, chromium, or arsenic during the manufacture of particleboard from CCA treated utility poles of red pine is negligible and insignificant at a 5% level, although the reduction of poles into particles involved high mechanical and thermal activities during the reduction of poles into particles with the hammermill and a high pressure of about 8.28 Mpa (1200 psi) level and 190°C temperature is used for particleboard formation.

Table 1 - Chemical retention in particles before and after particleboard manufacture

CCA Chemical	Retention in Particles Kg/m^3 (pcf)	Retention in Boards Kg/m^3 (pcf)
CuO	1.41 (0.09)	1.23 (0.08)
CrO_3	3.68 (0.23)	3.20 (0.20)
As_2O_5	2.84 (0.18)	3.04 (0.19)
Total Oxide	7.93 (0.50)	7.47 (0.47)

Table 2 lists the amount of heavy metal leached from particleboards made of virgin (V) and recycled (R) CCA treated furnish after a one month immersion in distilled water. The levels of copper and chromium released during the soaking period vary with the type of resin, the amount of resin, and the furnish used. Boards made of CCA treated furnish, evidently leached more Cu, Cr, and As than those made of virgin furnish. Boards made with high resin content (6%) leached less CCA components than those made of low resin content (2.5%). UFR boards leached more CCA components than PFR boards because PFR is water resistant.

Table 2 - CCA leachate content from particleboards after 28 days

Furnish Type	Resin Type	Resin Content %	[Cu] ppb*	[Cr] ppb	[As] ppm
Virgin	UF	2.5	60	200	0.28
		4	50	180	--
		6	40	120	0.04
	PF	2.5	30	--	--
		4	300	--	--
Reconstituted	UF	2.5	3200	2800	12.9
		4	2500	2400	17.7
		6	1430	1400	10.5
	PF	2.5	1000	800	25
		4	700	600	14
		6	700	700	14

Mechanical and Physical Properties

Tables 3 lists the ANSI A208.1-1993 requirements of mat formed medium density boards for MOE, MOR, and IB. The MOE, MOR, IB, TS, and WA values of boards made of UFR and PFR are summarized in Tables 4 and 5, respectively.

Table 3 - Some ANSI requirements of medium density particleboards

	MOE		MOR		IB	
Grades	kpsi	MPa	psi	MPa	psi	kPa
M-1	250.2	1725	1595	11	58	400
M-S	275.7	1900	1813	12.5	58	400
M-2 or PBU	326.3	2250	2103	14.5	65	400
M-3 or D2	398.9	2750	2393	16.5	80	551.6
D-3	449.6	3100	2828	19.5	80	551.6

The average density of reconstituted boards or boards made of virgin furnish was 750±50 Kg/m^3 (46.8±3.1 pcf) which corresponds to medium density. Their equilibrium moisture content (EMC) prior to testing was 5 ± 1 percent.

VUFR represent boards made of virgin (V) furnish using urea formaldehyde resin (UFR). RUFR is reconstituted (R) board made of CCA treated utility poles using urea formaldehyde resin. VPFR defines board made of virgin furnish with phenol formaldehyde resin (PFR). RPFR is reconstituted boards from CCA treated poles with phenol formaldehyde resin.

Urea formaldehyde particleboards

VUFR at 4% resin content met the ANSI requirements of MOE, MOR, and IB for grades M-1 for non-structural underlayment, M-S, M-2, or PBU for underlayment flooring products and M-3 or D2 for home decking materials. At 4% resin content, RUFR did not meet the grades M-3 or D2 MOE requirement, but satisfied the conditions when 6% resin content was used. Resin content could be used to increase the bending strength of reconstituted composites as illustrated in Table 4. The statistical significance of the effect of the resin content and the furnish on the MOE, MOR, and IB is also shown in Table 4. The MOE of VUFR boards with 2.5, 4, or 6% resin content were similar but the MOR of 6% resin content boards is higher than that of 4 or 2.5% resin content boards. The MOE of RUFR was more sensitive and increased with the resin content. MOE of 6% resin content of RUFR was similar to the MOE of VUFR at the same resin level, suggesting a probable maximum plateau for the resin contribution. At 6% resin content, the MOR of RUFR was similar to that of VUFR at 4%. At the low resin content (2.5 to 4%), the MOR of RUFR were lower than that of VUFR which was in agreement with literature data suggesting the reduction of properties of composites made of CCA treated wood (Vick, 1980; Archer et al., 1993). The MOR was more sensitive than the MOE and the IB.

A two-way analysis of variance (ANOVA) test conducted at a 95% level of confidence indicated that IB of RUFR was higher than that VUFR and also that the effect of resin content from 2.5 to 6 percent was insignificant (Table 4) on IB of furnish used. The reason for the higher IB values was not understood. Archer et al. (Archer, 1993) reported higher IB value of boards made of CCA treated wafers in contradiction with Schmidt (Schmidt, 1991, Boggio and Gertjejansen, 1982). Water absorption (WA) and thickness swelling (TS) of VUFR were reduced considerably and in agreement with the hydrophobicity created by CCA treatment. For RUFR at 4% resin content, WA was only 81% compared to 133% for VUFR. Water absorption and thickness swelling also decreased with the increase of resin content for reconstituted wood.

Phenol formaldehyde particleboards

The properties of boards made of phenol formaldehyde resin are included in Table 5. At 2.5% resin content VPFR boards met the M-1 and M-S requirements for MOE, MOR, and IB. VPFR can be used for commercial non structural underlayment. At 4% resin content, MOE, MOR and IB of VPFR was increased and M-2 or PBU conditions (Table 3) satisfied for home decking products.

Table 4 - Some mechanical and physical properties of UFR particleboards

Furnish	Resin Content	IB		MOR		MOE		TS - 2H	TS - 24H	WA - 2H	WA - 24H
Used	%	kPa	psi	MPa	psi	MPa	kpsi	%	%	%	%
Virgin	2.5	738	107 (b)	17.7	2572 (b)	3635	527 (a)	86%	103%	126%	148%
	4	738	107 (b)	18.8	2728 (b)	4026	584 (a)	73%	85%	113%	133%
	6	814	118 (b)	22.8	3305 (a)	3733	541 (a)	43%	58%	78%	101%
Recon	2.5	1076	156 (a)	11.8	1716 (c)	1878	272 (c)	36%	45%	77%	97%
	4	1131	164 (a)	16.8	2430 (c)	2651	385 (b)	26%	37%	55%	81%
	6	1393	202 (a)	19.1	2764 (b)	3672	533 (a)	16%	27%	44%	74%

Table 5 - Some mechanical and physical properties of PFR particleboards

Furnish	Resin Content	IB		MOR		MOE		TS - 2H	TS - 24H	WA - 2H	WA - 24H
Used	%	kPa	psi	MPa	psi	MPa	kpsi	%	%	%	%
Virgin	2.5	396	57 (d)	10.6	1533 (b)	2077	301 (b)	66%	71%	127%	137%
	4	831	121 (b)	17.1	2475 (a)	2749	399 (a)	38%	38%	92%	103%
Recon	2.5	633	92 (c)	9.0	1308 (b)	1643	238 (c)	51%	53%	97%	110%
	4	784	114 (b)	13.2	1911 (b)	2295	333 (b)	41%	42%	86%	97%
	6	1241	180 (a)	15.7	2270 (b)	2199	319 (a)	24%	25%	47%	50%

Within columns, means followed by the same letter are not significantly different at a 95% confidence level.

RPFR boards with 2.5% resin content met the M-1 grade requirement but fail to satisfy the M-S requirement. RPFR at 4% PFR satisfies the M-S conditions but not the M-2 compared to VPFR at 4%. Even at 6% resin content, RPFR did not meet the conditions for M-2 grades. Reconstituted wood composites with 4 to 6% resin content can be used for floor underlayment but not for home decking. The low WA and TS (Table 5) of reconstituted products are some of the advantages that can be exploited from using indicated CCA treated utility poles as furnish. Meanwhile, more research needs to be done to understand the low mechanical properties of reconstituted wood compared to those from virgin furnish. IB of RPFR was higher than that of VPFR and also increased with the resin content. The high IB of RPFR was not predictable based on available information, more work need to be done to explain the IB behavior.

<u>Decay resistance</u>

Urea formaldehyde particleboards

OSB made of CCA treated wafers has been reported to impart adequate decay and termite resistance under laboratory and field conditions (Archer et al., 1993). Decay tests were conducted with boards made of urea and phenol formaldehyde resin. Weight losses measured from an agar and also from soil block test are reported in Table 6. Weight loss of RUFR boards were generally low or insignificant compared to that of VUFR boards. The weight loss of UFR boards decreased with the increase of resin content confirming some bioactivity of the resin. Another advantage of reconstituted wood from CCA treated poles will be their durability when exposed to fungi.

Table 6 - Weight loss in percent of UFR particleboards exposed to fungi using modified soil block and agar block test methods

Test Type	Particles	Reconstituted			Virgin		
	Resin Content (%)	2.5	4	6	2.5	4	6
Agar Block	Control	1(2)	2(1)	1(2)	2(1)	1(2)	1(2)
	P. placenta	1(2)	1(2)	1(2)	29(5)	28(5)	13(7)
	G. trabeum	2(1)	1(2)	2(1)	37(12)	20(10)	7(3)
	P. ostreatus	1(2)	2(1)	1(2)	11(14)	25(5)	30(10)
	T. versicolor	1(2)	2(1)	1(2)	22(12)	20(5)	5(2)
Soil Block	Control	1(2)	2(1)	1(2)	39(1)	2(2)	2(1)
	P. placenta	1(2)	1(2)	1(2)	20(5)	15(5)	12(8)
	G. trabeum	2(1)	1(2)	1(2)	30(7)	21(3)	15(6)
	P. ostreatus	2(1)	1(2)	2(1)	42(6)	27(10)	42(5)
	T. versicolor	1(2)	1(2)	1(2)	20(7)	18(3)	2(2)

Numbers in parentheses represent standard deviation

Phenol formaldehyde particleboards

A soil block decay test was performed on boards made with 2.5 and 4 percent PFR and results are shown in Table 7. Little or no decay occurred using PFR at any content on boards made with CCA treated furnish. Virgin boards did, however, show weight loss due to decay.

Table 7 - Weight loss of PFR particleboards using a modified soil block test

Furnish used	virgin		reconstituted	
Resin content	2.5%	4%	2.5%	4%
Control	0(0)	0(0)	0(0)	0(0)
G. trabeum	24(27)	0(0)	0(0)	0(0)
P. ostreatus	0(0)	0(0)	0(0)	0(0)
P. placenta	44(22)	18(28)	0(0)	0(0)
T. versicolor	10(24)	0(0)	0(0)	0(0)

Standard deviations are in parentheses

CHAPTER 3

STUDY II: EVALUATION OF PARTICLEBOARDS MADE WITH DIFFERENT TREATED WOOD PROPORTIONS

Objective

The objective of this study was to investigate the effect of increasing the CCA treated wood proportion in particleboards on some mechanical and physical properties. Special care was taken to ensure particle size was the same for both virgin and treated particles. In a previous study, acceptable bending strength was attained with a liquid phenol formaldehyde(PF) at 4 and 8 percent. The same resin levels were used in this study.

Materials and Methods

Materials

Untreated and CCA treated red pine *(Pinus resinosa Ait.)* poles were obtained from Hydrolake Leasing Service in McBain, Michigan. All poles were kiln-dried to 30 percent moisture content (MC) prior to treatment. Half of the poles were then pressure treated with a 2 percent total oxide solution of CCA-C for 6 hours with a modified full-cell method. The treatment included an hour of initial vacuum at 91 kPa (27 inches) of mercury followed by 4 hours of pressure at 1.03 MPa (150 psi), and a final vacuum of 1 hour. The target retention of total oxides in the poles was 9.6 kg/m^3(0.60 pcf). The treated poles were then air-dried to 19 percent MC.

Particle Manufacture Methods

Poles were chipped with an Morbark Eager Beaver Chipper, and chips reduced into particles with a laboratory hammermill. Particles from untreated red pine were virgin furnish and particles from CCA treated red pine named treated furnish.

Special care was taken for particle size to avoid imbalance which could create panel warping and strength reduction. Particles were sifted by size with a vibrating inclined screen, and only particles passing through 10 but held by 16 mesh screens were selected for particleboard production. A screen analysis was performed on a sample of both particle types with an electric shaker for 5 minutes using screen 8, 10, 16 and 30 mesh. The thickness, width, and length of 1000 screened particles were also measured by light microscope. Screened particles were air dried to 5±2 percent MC and used to manufacture particleboards.

The pH of both furnishes was determined by using a pH meter. In a beaker, 10 g of screened particles were mixed in 100 ml of distilled water for 30 minutes using a sonicated bath and the pH determined.

Composite Manufacture Methods

Treated and virgin particles were mixed at five proportions by weight, namely 100, 75, 50, 25, and 0 percent treated wood content. These mixtures were then sprayed with GP© 107C38 RESI-STRAN Oriented Strand Board phenol-formaldehyde resin (PF) containing 55 percent resin solids. Ten replicates were manufactured at each proportion of treated wood content with 8 percent resin solids, while 6 particleboards were manufactured at each proportion of treated wood content with 4 percent resin solids. Overall a total of 80 boards were fabricated.

Particle mixtures were sprayed with resin in a laboratory rotary drum blender for 5 minutes and mats were hand-formed in a 40.6 cm square (16" square) frame. The MC of the particles in the mat before pressing was 8±2 percent. A Berthelsen thermo-oil heated hydraulic press was used to press the mat between two steel platens down to a nominal thickness of 10 mm (0.375"). The time interval from the application of resin to pressing was kept constant at 5 minutes in all trials. The press time was 6 minutes, the pressure 800 psi (8.28 MPa), the press temperature 190°C (325°F), and the closing time 13 seconds.

Low density areas on each board were removed by trimming one inch on all edges. Trimmed boards were kept at 65 percent relative humidity (RH) and 20°C (68°F) for at least 40 days before testing or until they reached their equilibrium moisture content (EMC). The EMC and density of boards were 5±1 percent and 750±50 kg/m^3(47±3 pcf), respectively.

Material Testing Methods

Samples were cut from each board to conform with American Society for Testing Materials (ASTM) Standard number D1037-95 guidelines to obtain: 2 specimens for bending, 3 for thickness swelling (TS) and water absorption (WA), and 6 for internal bond (IB) (2) (See Figure 1). Samples were stored in a room conditioned at 65 ± 1 percent RH and temperature of 20±3°C(68± 6°F) until tested. ASTM Standard 1037-95 tests for static bending and IB were all conducted using an Instron testing machine (2). TS and WA were conducted by ASTM Standard 1037 as well.

Leaching Test Method

A modified American Wood Preservers' Association (AWPA) (3) leaching test was also performed on each board type as follows: two liters of water were added to twelve 7.62 cm by 7.62 cm by 1 cm (3" by 3" by 0.375") samples in a plastic container with a cover to reduce water evaporation. Aliquots of the leachate were taken every three to five days for 28 days and analyzed for chromium, copper, and arsenic content.

Determination of CCA Retention in Particleboard

An ASOMA X-ray Fluorescence Analyzer, Model 100, provided by Universal Forest Products in Grand Rapids, MI, was used to determine the concentration of chrome, copper, and arsenic in the finished particleboard product at each level of treatment (0, 25, 50, 75, and 100 percent CCA-treated wood). Samples of 5 grams from 3 random boards at each treatment level were taken, ground, and oven-dried at 100 ± 3° C (212 ± 6° F) for 1 hour. The samples were then analyzed at a density of 750 ± 50 kg/m^3 (47 ± 3 pcf) on the ASOMA.

Results and Discussion

Particle Size Analysis

Since the same method of particle manufacture was used as in the first study, the results of analysis were the same.

Particle length, width, and size distribution are summarized in figures 2, 3, and 4, respectively. About 80 ± 5 percent of the thousand particles analyzed by light microscopy had an average length of 3.6 ± 1.0 mm (0.14 ± 0.04") and an average width of 1.5 ± 0.3 mm (0.06 ± 0.01"). The average slenderness ratio was 2.64: 1, which is defined as the ratio of length to the diameter of the particle. From the Tyler sieve analysis, Figure 4 depicts particle size ranged from 0.5 to 2.3 mm (0.02 to 0.09"). This shows the same distribution for both treated and untreated furnish by weight. Eighty-seven percent of all particles were between 1.52 and 1.78 cm (0.06 and 0.07") in size. This data is in agreement with microscopy measurements based on distribution and standard deviation. Any differences between microscopy and Tyler sieve data could be explained by the many angles at which particles could pass through the Tyler sieves (0 - 180 degrees).

Particle pH

Since the same particles were used in Study II as in Study I, the particle pH was the same. The results are summarized again here.

The particle pH was found to be slightly different for virgin versus treated particles. Virgin particles had a pH of 4.9 compared to 5.1 for the CCA-treated furnish. However, pH obtained through this method is not representative of the pH of the wood surface since the pH meter evaluates the concentration of H^+ liberated in the water medium. Therefore the pH could be influenced by the solvent. Thomason and Pasek (1997) have shown that pH of southern yellow pine tested in water is different than tested in acetone. Knowing the low pH of CCA (pH ≅ 2), the similarity in pH of CCA-treated and virgin red pine suggest that wood may behave as a buffer, or the retention of CCA in the wood analyzed was low.

Mechanical and Physical Properties

Effect of resin content

The MOR, MOE, and IB of reconstituted particleboards made with 4 and 8 percent solid resin content with increasing amounts of CCA treated particles are shown in Tables 8, 9 and 10, and Figures 5, 6, and 7.

Table 8 - Bending, IB, and physical properties of particleboards made with CCA treated furnish: 4% PF resin

Treated Particles	IB		MOR		MOE		TS - 2H	TS - 24H	W A - 2H	W A - 24H
%	kPa	psi	kPa	psi	MPa	kpsi	%	%	%	%
0	1330.0	192.9 (a)	13885.4	2013.9 (a)	1354.8	196.5 (a)	33.5%	33.7%	73.5%	87.5%
25	1301.7	188.8 (a)	12068.6	1750.4 (a)	1365.9	198.1 (a)	31.7%	34.0%	74.2%	87.0%
50	1264.5	183.4 (a)	11820.4	1714.4 (a)	1539.6	223.3 (a)	31.0%	34.0%	73.4%	86.5%
75	1179.0	171.0 (a)	8939.7	1296.6 (b)	1223.8	177.5 (a)	33.3%	36.0%	73.2%	84.7%
100	900.5	130.6 (b)	9703.0	1407.3 (b)	1888.5	273.9 (b)	35.9%	38.9%	78.4%	88.7%

Table 9 - Bending, IB, and physical properties of particleboards made with CCA treated furnish: 8% PF resin

Treated Particles	IB		MOR		MOE		TS - 2H	TS - 24H	W A - 2H	W A - 24H
%	kPa	psi	kPa	psi	MPa	Kpsi	%	%	%	%
0	N.A.	N.A.	18457.3	2677.0 (a)	2735.8	396.8 (a)	20.1%	23.6%	45.8%	57.8%
25	N.A.	N.A.	18637.9	2703.2 (a)	2733.1	396.4 (a)	19.3%	20.6%	49.5%	61.6%
50	N.A.	N.A.	16937.7	2456.6 (a)	2630.4	381.5 (a)	19.7%	21.7%	45.9%	56.6%
75	N.A.	N.A.	13323.4	1932.4 (b)	2269.1	329.1 (b)	21.3%	23.7%	59.0%	66.7%
100	N.A.	N.A.	13813.7	2003.5 (b)	2000.2	290.1 (b)	24.0%	27.7%	54.4%	65.7%

Means followed by the same letter are not significantly different at a 95% confidence level

Table 10 - Effect of PF resin content on particleboard properties

	IB	MOR	MOE	TS-2	TS-24	WA-2	WA-24
0	-	33%	102%	-40%	-30%	-38%	-34%
25	-	54%	100%	-39%	-40%	-33%	-29%
50	-	43%	71%	-36%	-36%	-37%	-35%
75	-	49%	85%	-36%	-34%	-19%	-21%
100	-	42%	6%	-33%	-29%	-31%	-26%

% change =$[(P_8 - P_4) / P_4] * 100$

where P = property value

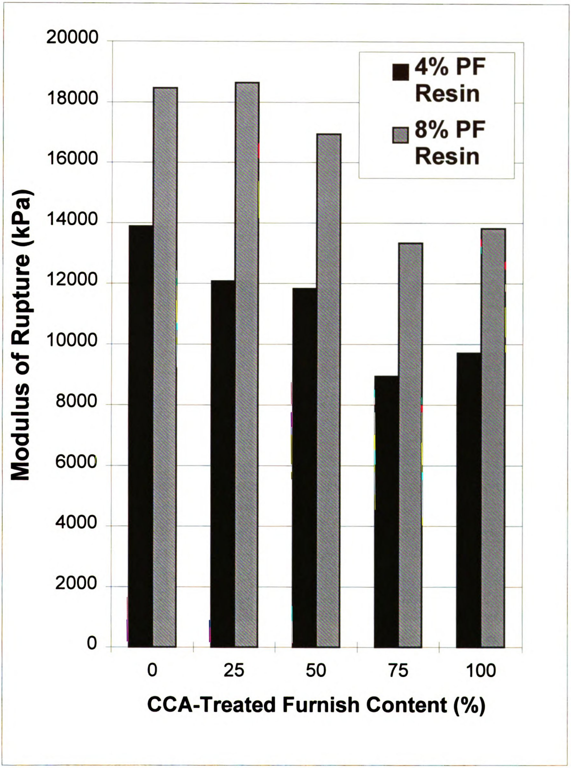

Figure 5 - MOR of particleboards made with untreated and treated particles

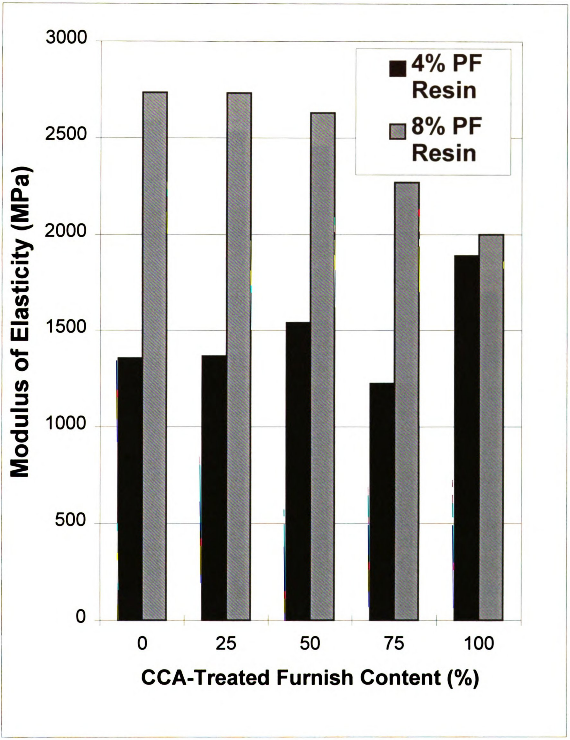

Figure 6 - MOE of particleboards made with untreated and treated particles

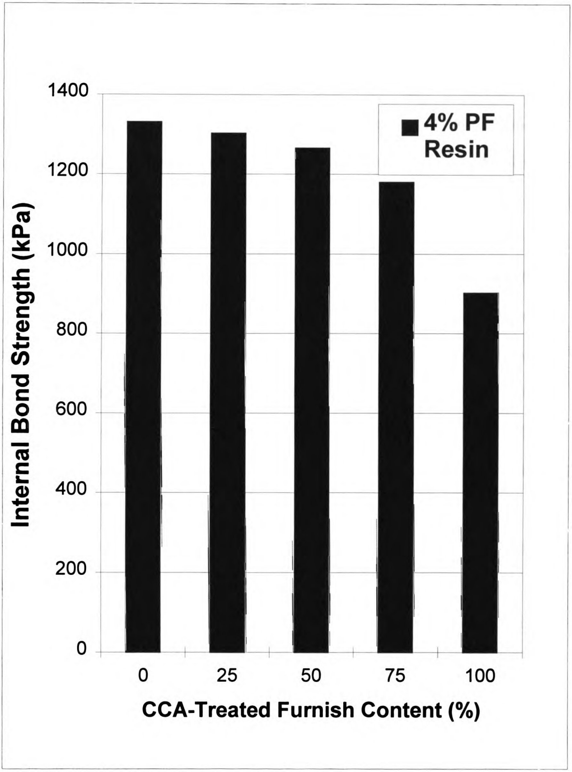

Figure 7 - IB of particleboards made with untreated and treated particles

Results show that 8 percent PF board property values were substantially higher than those made with 4 percent PF. As expected, increasing the resin content increased the properties of the board in agreement with the literature (Boggio et al., 1982, Gertjejansen et al., 1988; Vick, 1980; Vick et al., 1990; Vick et al., 1996). The increase of PF resin content from 4 to 8 percent, resulted in a 33 percent increase in MOR for boards made of virgin furnish, and an increase of 45 ± 5 percent for other boards containing treated furnish.

The MOE of boards containing 0 or 25 percent treated furnish increased 100 percent when 8 percent PF was used compared to 4 percent PF. The MOE of boards containing 50 or 75 percent treated wood increased by an average of 78 percent by doubling the resin content. When using 100 percent treated wood the MOE did not change when applying 8 percent instead of 4 percent PF resin (Table 10). The MOE ws reduced either because of a low resin content or the particle aspect ratio was not large enough.

The IB values for 4 percent PF boards are shown in Figure 6. The IB strength for boards made of 8 percent PF were over the limit of the load cell available.

The only differences in TS or WA found in this study were between boards made of 4 or 8 percent PF resin. Boards made with 8 percent PF swelled 37 percent less than those made with 4 percent PF after 2 hours. After 24 hours, TS decreased by 33 percent by using 8 instead of 4 percent PF. Also, 8 percent boards absorbed 32 percent less water after 2 hours compared to 4 percent boards. After 24 hours, boards made with 8 percent PF absorbed 29 percent less water than boards made with 4 percent PF. This can be explained by PF being an exterior resin used for water-resistant applications. As expected, increasing resin content decreases thickness swelling and water absorption.

Effect of CCA-treated wood content

MOR, MOE, and IB are reduced when a greater proportion of treated particles were used. These findings are consistent with the literature (Boggio et al., 1982, Gertjejansen et al., 1988; Vick, 1980; Vick et al., 1990; Vick et al., 1996). The reduction in mechanical properties has been explained by the incompatibility of PF resin bonds with CCA treated wood (Boggio et al., 1982, Gertjejansen et al., 1988; Vick, 1980; Vick et al., 1990; Vick et al., 1996). It has been suggested that insoluble chromium, copper, and arsenic solids present on the cell walls may reduce the formation of bonds between adhesives and wood. Recently it has been attributed to the reduction of wood cell physical and mechanical properties due to loss of some cell wall components during CCA treatment (22). Winandy et al. (1997) reported that CCA treatment reduces the extractive content, and up to 20 percent of the hemicellulose in wood.

The use of 50 percent CCA-treated wood content in the manufacture of particleboard did not affect the MOR, MOE, and IB significantly. At 75 percent treated wood content, the MOR was significantly different than the MOR at 0, 25, and 50 percent treated wood content. The IB and MOE were reduced significantly only for samples containing 100 percent CCA-treated wood.

Dimensional stability (Tables 8 and 9) was not affected by the proportion of CCA-treated wood in the particleboard. Table 10 gives the effect of PF resin content on the change in TS and WA. The TS and WA for boards made with 4 or 8 percent PF were not affected significantly by the treated wood content.

Statistical Analysis

A statistical analysis of mechanical and physical properties was executed. A Tukey two-way ANOVA was used to make simultaneous pairwise comparisons between dependent data sets using two independent variables. The treated wood content and resin content were used as the independent variables. Data was analyzed to test if the distributions were normal and if the variances were equal in order to compare the data with significance. All tests were compared with 95 percent confidence.

Determination of CCA Retention in Particleboard

The results of ASOMA analysis of particleboard CCA concentrations are shown in Table 4. As expected, the actual quantities of chromic oxide, copper oxide, and arsenic pentoxide gradually increase with nominal treated wood concentration. The oxide concentrations in the boards made with 8 percent PF resin were insignificantly different with oxide concentrations in boards made with 4 percent PF resin. The retentions of CCA in kg/m^3 in the boards were higher than that of the poles because the density of the particleboard was about twice that of red pine. Red pine wood has a density of 385 kg/m^3 (24 pcf) while the board densities were 750 kg/m^3 (47 pcf).

Table 11 - Actual concentrations of CCA in the particleboards

Nominal Concentration	Assumed retention[1]		Actual Concentrations of 4% PF Particleboards							
			CrO_3		CuO		As_2O_5		Total	
%	Kg/m^3	pcf	Kg/m^3	pcf	Kg/m^3	pcf	Kg/m^3	pcf	Kg/m^3	pcf
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	2.40	0.15	1.20	0.08	0.50	0.03	1.03	0.06	2.74	0.17
50	4.81	0.30	2.89	0.18	1.18	0.07	2.31	0.14	6.37	0.40
75	7.21	0.45	3.79	0.24	1.68	0.10	3.31	0.21	8.78	0.55
100	9.61	0.60	5.67	0.35	2.48	0.16	4.69	0.29	12.85	0.80

Nominal Concentration	Assumed retention[1]		Actual Concentrations of 8% PF Particleboards							
			CrO_3		CuO		As_2O_5		Total	
%	Kg/m^3	pcf	Kg/m^3	pcf	Kg/m^3	pcf	Kg/m^3	pcf	Kg/m^3	pcf
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	2.40	0.15	1.30	0.08	0.50	0.03	1.05	0.07	2.86	0.18
50	4.81	0.30	2.16	0.13	1.05	0.07	2.16	0.13	5.37	0.34
75	7.21	0.45	3.49	0.22	1.46	0.09	2.86	0.18	7.80	0.49
100	9.61	0.60	4.74	0.30	1.98	0.12	3.86	0.24	10.59	0.66

[1]Based on pole retention.

Leaching Test Results

Leaching test results are shown in Table 5. Chromium, copper, and arsenic in the leachate were analyzed over a 28 day period for 4 percent PF boards and over a 14 day period for 8 percent PF boards. The corresponding metal oxides were calculated assuming that copper was present as copper oxide (CuO), chromium as chromium trioxide (CrO_3), and arsenic as arsenic pentoxide (As_2O_5) (See Appendix B). These leaching results are expressed in percent of initial CCA oxides present in the particleboard.

Table 12 - Leaching as a percent of the initial total oxides in the particleboards

	4% PF after 14 days			8% PF after 14 days			4% PF after 28 days		
Nominal Concentration	CrO_3 (%)	CuO (%)	As_2O_5 (%)	CrO_3 (%)	CuO (%)	As_2O_5 (%)	CrO_3 (%)	CuO (%)	As_2O_5 (%)
0	0	0	0	0	0	0	0	0	0
25	0	0	2	0	0	1	0	0	3
50	0	0	2	0	0	1	0	0	2
75	0	0	1	0	0	1	0	0	2
100	0	0	1	0	0	1	0	0	2

As shown in Table 12, negligible amounts of CCA were leached from the particleboards after 14 and 28 days. No CrO_3 and CuO were leached at all, while 1 to 3 percent of the arsenic pentoxide was leached. These values were within the error of the equipment used.

Comparison to ANSI Requirements

Finally, in comparison with ANSI standard A208.1-1993 for medium density particleboards, 4 percent PF boards with 0 and 25 percent treated wood satisfied the requirements for an M-1 grade for IB and MOR. These boards failed MOE requirements.

All other 4 percent PF boards passed an M-1 grade for IB. Boards made with 8 percent PF and 0, 25, and 50 percent treated furnish passed requirements for an M-2 grade, while 75 and 100 percent treated furnish passed an M-S grade. Both M-2 and M-S are grades used for particleboard underlayment or subflooring. These results show that a maximum of 50 percent CCA treated particles can be incorporated in particleboard if an 8 percent PF resin content is used for the manufacture of underlayment or subflooring.

Comparison Between Study I and Study II

Properties of boards made in Study I were not similar to those produced in Study II with the same type and amount of resin and the same proportion of CCA treated wood. The discrepancy cannot be explained and this may represent a major problem of this study. However, several speculative explanations can be given with regard to the variability.

The most probable reasons could be the control of manufacturing parameters. The press closing times used in this study were shorter (9 to 15 seconds) than the commercial practice consisting of a minimum of 30 to 45 seconds (Suchsland, 1986; Chow, 1984) necessary to reduce density variation within a board. A short closing time is known to create variable MOE, MOR, and IB within a board. An appropriate close time would have reduced the density variability, as well as made the MOE, MOR, and the IB more consistent.

The second oversight was using two different batches of furnish of CCA treated red pine. Each study was performed with a limited amount of CCA treated fiber, and therefore, a second batch was required to complete the study. This was a limited amount because boards were made at first with 8 percent instead of 4 percent PF in the second study due to board calculation error. This may have changed property values significantly between Studies I and II.

Finally, the third overlooked possibility was using industrial-commercial resins. We didn't want to vary or change the glue type, but Georgia-Pacific had been using one formulation when the first study was initiated, and a second resin when the second study began. The objective of the study was to determine feasibility without specific concerns on glue, and whether or not we could satisfy the requirements for particleboard. It was assumed that the properties would not significantly change due to the resin formulation. This may not have been true.

CHAPTER 4

CONCLUSIONS

From the results of the first study, reconstituted particleboards can be made from red pine utility poles treated with CCA at 0.60 pcf using UFR or PFR. A level of 4 to 6 percent resin content was needed to produce boards with bending properties comparable to those made of virgin furnish. With 4 percent or more resin content ANSI requirements for medium density mat formed particleboards for underlayment were satisfied. Water absorption capacity, thickness swelling, and biological durability were improved for reconstituted boards. The amount of metal leached from the boards was negligible.

For the second study, particleboards were manufactured containing 0, 25, 50, 75, and 100 percent CCA treated red pine utility poles and bonded with 4 or 8 percent liquid PF resin. From the results, no significant difference was found between boards made of 50 percent treated wood and untreated particleboard in mechanical and physical properties, but to meet ANSI requirements a higher resin content should be utilized. The MOE, MOR, and IB strength were reduced significantly when the board contained 75 percent CCA treated particles at both 4 and 8 percent solids resin content. There was no significant change in dimensional stability due to the amount of treated furnish used, but there was a difference of up to 35 percent when using a higher resin content.

CHAPTER 5

RECOMMENDATIONS

This study showed that reconstituting freshly treated wood to make particleboards was feasible with 50 percent treated wood content and 8 percent PF resin with short close times. Longer close times should be used in future studies to reduce density variation.

In the future, it may be feasible to manufacture wood composites with a mixture of recycled wood materials and freshly treated wood or virgin materials, but not using 100 percent recycled wood materials. Further studies on the actual recycling of decks into wood composites is imperative to understand the feasibility of it and to reduce the amounts of CCA treated wood that will go to landfill each year.

Additionally, an analysis of the costs and benefits of this type of recycling is necessary. Understanding the impact on particleboard producers is important to the implementation of such a production.

Finally, as shown in this study, the leaching of reconstituted particleboards from CCA treated red pine is negligible. Further investigations of the leaching of CCA from reconstituted particleboards need to be investigated further to confirm these results.

APPENDICES

APPENDIX A

APPENDIX A

Sample Calculation Worksheet of Particleboard Production

Final (target) board dimensions: 15" x 15" x 0.375"

$Volume_{OD}$ of target board: 15" * 15" * 0.375" = 84.375 in^3

$Volume_{OD}$ of target board conversion: 84.375 in^3 * (2.54 cm/in)^3=1383 cm^3

Target board $density_{OD}$: 0.75 g/cm^3 (Allowable range: 0.70-0.80 g/cm^3)

Target board $Mass_{OD}$: 0.75 g/cm^3 * 1383 cm^3 = 1038 g

Resin solids (dry): 4% 1038 g * 0.04 = 41.52 g

Particles (dry): 96% 1038 g * 0.96 = 996.48 g

Table 13: Resin specifications

Resin type	PF	UF
Solid content	53%	55%
Specific gravity	1.219	1.270

<u>Add moisture content of 3.5%</u>

Mass of particles with water: 996.48 g / (1-MC) = 1033 g

Mass of liquid resin: 41.52 g / 0.55 = 75.49 g

Liquid volume of resin: 75.49 g / 1.270 = 59 ml

Mat weight: 1033 g + 75.49 g = 1108 g

APPENDIX B

APPENDIX B

Leachate Calculations

First, convert metal in leachate to total mg of oxide leached.

Example:

$$\frac{XpartsCr}{millionH_2O} \times \frac{CrO_3}{Cr} = \frac{XmgCrO_3}{LH_2O}$$

$$\frac{XmgCrO_3}{LH_2O} \times LH_2O = XmgCrO_3$$

Second, determine how many milligrams of metal oxide were in the particleboard to begin with.

Example:

Determine total milligrams of wood:

12 samples with 0.75 g/cm^3 density,

and volume of 10.16 cm x 10.16 cm x 1 cm = 103.2 cm^3

Total volume: 12 x 103.2 cm^3 = 1238.7 total cm^3

Total mass: 1238.7 cm^3 x 0.75 g/cm^3 = 929 g of particleboard, or 929,000 mg

Then find milligrams of metal oxide in that wood:

R = Retention of CrO_3 in percent

R x 929,000 mg = CmgCrO_3

where C = mg of metal oxide in particleboard

Finally, make a percentage that leached of the total CCA oxide initially present in the board.

$$\boxed{\frac{XmgCrO_3Leached}{CmgCrO3initial} \times 100 = \%CrO_3Leached}$$

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