Physical and mechanical properties of flakeboard produced from recycled CCA-treated wood

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Abstract

Chromated copper arsenate (CCA) treated wood has been most widely used in North America since the 1970s for many exterior applications such as decks, fences, playground equipment, utility poles, and others. A large volume of CCA-treated wood is currently coming out of service. Traditional disposal methods such as landfilling and incineration are not without adverse environmental outcomes. Recycling CCA-treated wood into composite products is one alternative to ease the disposal problem. 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, and decay resistance properties 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 median ratio with 50 percent of CCA-treated wood and untreated wood was found to be the optimum combination. In this case, residual CCA level was sufficient enough to prevent substantial weight losses in the decay tests, but low enough so that panel mechanical and physical properties were not substantially reduced.

Chromated copper arsenate (CCA) has been widely used to treat exterior wood in North America for many uses, including decks, gazebos, playground equipment, landscape timbers, agricultural stakes, marinas, and utility poles. 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 m^3) of lumber treated with CCA are produced annually in the United States (Micklewright 1998). 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 (1993a) 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 generally regarded by the public as having negative environmental consequences. It should be noted that incineration can be done in a cement kiln with the proper controls. Nonetheless, both options are expensive. There are increasing public concerns 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, 1996). The recycling option is potentially economically feasible and definitely environmentally attractive; recycling into wood composite products can be regarded as the most viable option (Felton and DeGroot 1996, Cooper 1999). Moreover, the significant quantities of residual CCA content in the wood can still have preserving capability

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*Forest Products Society Member.

Forest Prod. J. 54(2):89-94.

Table 1. — Experiment design.

Treatment	Rati A flakes vs. untreated flakes (%)
Group 1	100 : 00
Group 2	75 : 25
Group 3	50 : 50
Group 4	25 : 75
Group 5	0 : 100
Group 6[a]	Fresh southern pine sapwood
Group 7[a]	Out-of-service CCA-treated southern pine guardrail

[a]Groups 6 and 7 are two reference groups, which were only introduced in decay-resistance tests.

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).

It is generally known that CCA-treated wood is more difficult to properly bond in many applications than untreated wood. 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, Hall et al. 1982, Jeihooni et al. 1994, Felton and DeGroot 1996, Vick et al. 1996, Munson and Kamdem 1998, Lebow and Gjovik 2000, Clausen et al. 2001). 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, Vick et al. 1996, Munson and Kamdem 1998). It was found that a hydroxymethylated resorcinol-coupling agent could enhance physical and mechanical properties, particularly internal bond (IB) strength, of CCA-treated flakeboards (Vick 1996,1997). Schmidt et al. (1994) and 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 board strength 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. Also, Jeihooni et al. (1994) stated that flakeboard treated with CCA preservative showed good resistance to brown-rot fungus.

However, there is little data about the feasibility and properties of flakeboard from recycled CCA-treated southern pine (*Pinus* spp.) wood in the literature. Therefore, the objective of this study was to determine the physical and mechanical properties of flakeboard produced from CCA-treated wood.

Materials and methods

Raw materials

Twenty-five highway guardrail posts manufactured from southern pine (*Pinus* spp.) were obtained from Arnold Forest Products Company in Shreveport, Louisiana. The posts, which had been treated with CCA, went into 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 diameter range of 6-1/2 to 8-3/4 inches (16.5 to 22.2 cm). They were treated to 0.5 pcf (8.0 kg/m^3) and had been placed 38 inches (96.5 cm) into the ground. The fresh southern pine lumber was purchased at a local retail lumber store.

Flake manufacture

The posts were sawn into lumber, then randomly selected boards were cut into blocks 3 inches (7.6 cm) wide and 1 inch (2.5 cm) thick. The blocks were submerged in tap water for 24 hours and flaked with a laboratory ring-flaker to produce flakes measuring approximately 3 by 1 by 0.05 inches (7.6 by 2.5 by 0.1 cm). Although a longer soaking time would have resulted in higher quality flakes, it would have also resulted in leaching of the preservative and water-soluble wood extractives. The 24-hour soaking time was used to minimize the leaching effect. Virgin untreated flakes were produced with the same procedures. All flakes were dried in a forced-air oven maintained at 217± 4°F (102 ± 2°C) to obtain a mean moisture content (MC) of 4 percent. The flakes were screened to remove fines (material passing through a screen with 1/4 inch^2 (1.6 cm^2) openings).

Panel fabrication

Recycled CCA-treated flakes and untreated flakes were mixed at five ratios by weight: 100, 75, 50, 25, and 0 percent treated wood content **(Table 1)**. To prepare each panel, flakes were weighed and placed in a rotating drum blender. Phenol-formaldehyde (PF) adhesive obtained from Borden Chemical, Inc., in an amount equal to 4.5 percent of the ovendry weight of flakes, was weighed and applied by air-atomizing nozzles. The resin was a typical 50 percent resin solids commercial PF resin for oriented strandboard (OSB). The mean MC of the flakes after spraying was 8 percent.

After blending, the randomly oriented flakes were carefully hand felted into a 16.5- by 20-inch (41.9- by 50.8-cm) box to form the mat. The mats were then immediately transferred to a 20- by 20-inch (50.8- by 50.8-cm) single-opening hot-press with the platen temperature regulated at 370°F(187.8° C). Sufficient pressure, approximately 550 psi (3.79 MPa), was applied so that the platen closed to 0.5-inch (1.27-cm) thickness and stopped in approximately 30 seconds. Press time was 3.5 minutes after closure. Panels were conditioned for 1 week at ambient conditions prior to testing. Each of the five treatments combinations was replicated twice.

Physical and mechanical property tests

Flakeboards were trimmed to 14 by 18 inches (35.6 by 45.7 cm) and cut into specimens for testing according to the following standards: American Society

Table 2. — Physical properties of flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

Treatment	Ratio of CCA flakes vs. untreated flakes	Thickness	SG[a]	MC[b]	Linear expansion	Thickness swell	Water absorption
	(%)	(in.)		(%)			
Group 1	100:0	0.47	0.76	7.8	0.32	26.2	103
Group 2	75:25	0.47	0.76	7.6	0.31	28.4	100
Group 3	50:50	0.48	0.76	7.6	0.20	31.3	94
Group 4	25:75	0.48	0.76	7.3	0.26	33.2	98
Group 5	0:100	0.48	0.79	7.1	0.27	32.0	99

[a]SG = specific gravity, ovendry-based weight, and air-dry-based volume.
[b]MC = moisture content at the time of testing.

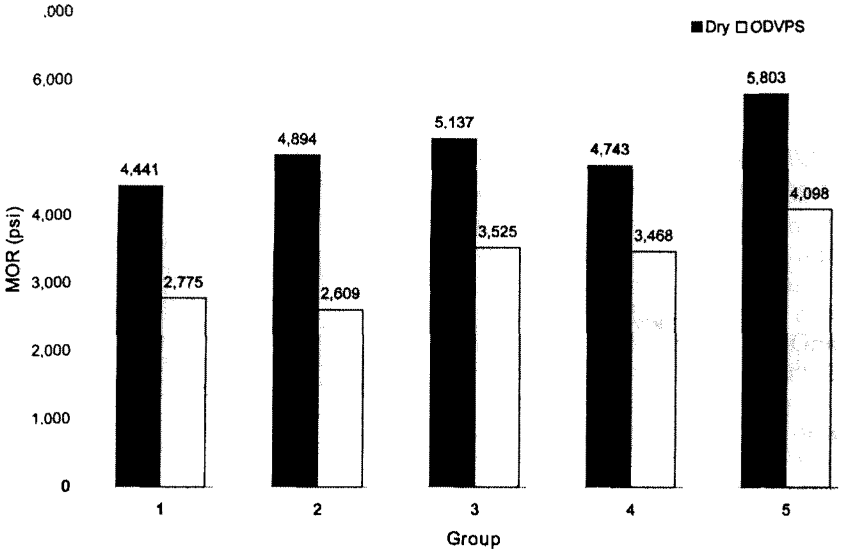

Figure 1. — Contrast of MOR between dry and ODVPS flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

for Testing Materials (ASTM) D 1037-93 (1998), APA–The Engineered Wood Association Standard P-1 (1997), and American Wood-Preservers' Association (AWPA) standard E-10 (2000). A minor modification was that the sample dimensions for the static bending tests and dimensional stability tests were 2 by 14 inches (5.0 by 35.6 cm). Mechanical property tests were conducted with specimens in the dry condition as well as following an ovendry vacuum pressure soak (ODVPS) treatment. There were 2 samples for bending strength tests, 2 samples for dimensional stability tests, and 12 samples (2.0 by 2.0 in. [5.1 by 5.1 cm]) for IB tests for each panel.

Decay resistance tests

The soil block procedure for decay was done with panel samples measuring 0.5 by 0.5 by 0.5 inch (2.7 mm^3). Weight loss was used to measure panel decay resistance. 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 comparative purposes, 10 blocks of untreated southern pine sapwood and CCA-treated guardrail posts sapwood (reference groups) were also subjected to each fungus. The guardrail posts tested were the same raw material used for flakeboard fabrication. The only leaching that occurred was the leaching of the guardrails during the softening period prior to flaking. The reference samples for the decay test were not leached.

Statistical analyses

Data of mechanical and physical properties and decay resistance were subjected to analysis of variance (ANOVA) to evaluate the effect of CCA-treated wood content in the flakeboard furnish. A Dunnett test was used to test comparisons of all treatments against a control. In mechanical and physical property tests, Group 5 with 100 percent untreated virgin wood content was considered as a control. Also, the guardrail and fresh southern pine specimens were introduced as two separate reference groups in decay-resistance tests. Statistical significance of difference between the groups was analyzed at the $\alpha = 0.05$ level.

Results and discussion

Mechanical and physical properties

The mechanical and physical properties of flakeboards are summarized in **Figures 1, 2,** and **3**, and **Table 2**, respectively. The ANOVA did not detect statistically significant differences for modulus of rupture (MOR) or modulus of elasticity (MOE) for both dry and ODVPS samples.

The data in **Figure 1** indicate that the boards with 100 percent untreated flakes had the highest MOR and MOE values. Although the analysis of variance showed that the group effect resulted in no significant difference, the mean MOR and MOE values decrease as the CCA-treated flake proportion increases (**Fig. 1** and **2**). This trend agrees with previous findings (Boggio and Gertjejansen 1982, Hall et al. 1982, Jeihooni et al. 1994, Felton and DeGroot 1996, Vick et al. 1996, Munson and Kamdem 1998, Lebow and Gjovik 2000, Clausen et al. 2001). Maloney (1986) stated that flake geometry exerts the dominant control over bending strength. The relatively undamaged, long, flat flakes afforded boards higher bending strength. During flakeboard manufacturing, it was visually observed that untreated virgin flakes have a rectangular flat shape and

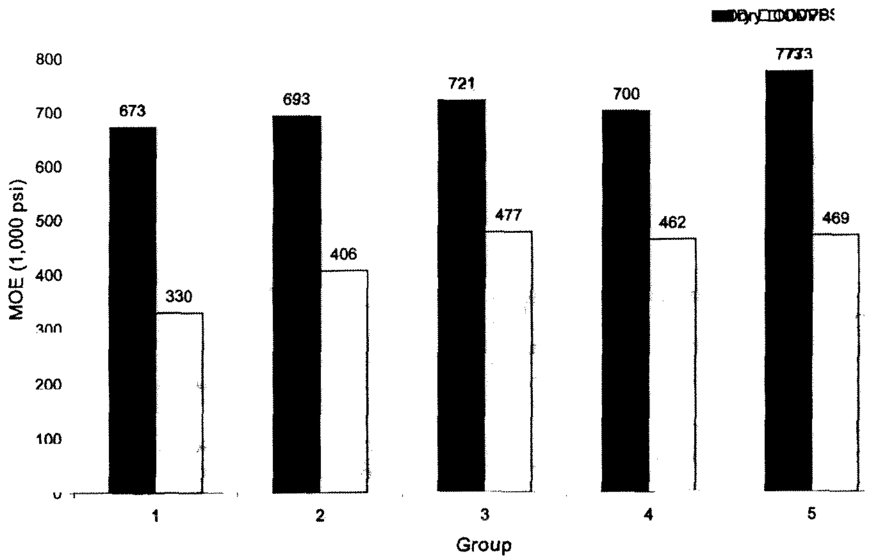

Figure 2. — Contrast of MOE between dry and ODVPS flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

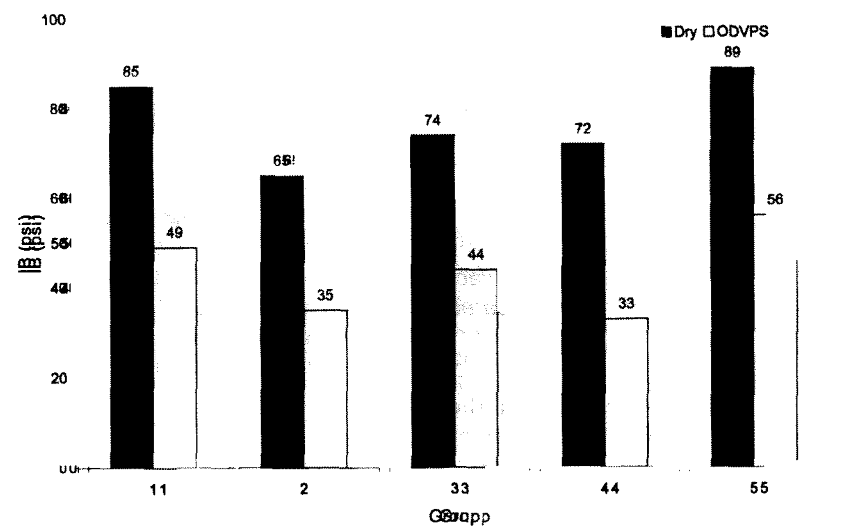

Figure 3. — Contrast of IB between dry and ODVPS flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood.

uniform size. However, the flakes from recycled CCA treated guardrails generated more fine particles. According to the rule of mixture, the higher the percentage of CCA-treated flakes a panel contains, the lower the bending strength of the panel. Therefore, the bending strength value should increase as the percent of CCA-treated flakes decreased from Group 1 to Group 5. In general, this trend was observed with the exception of Group 4.

There are several reasons to explain why flakes produced from guardrails contained more fines. First, the wood was largely obtained from plantation, small-diameter trees, which have a higher percent juvenile wood content. Juvenile wood is known to be less desirable for most processing operations because of its lower density and physical and mechanical properties. Secondly, the guardrails had been in service in exterior conditions for 13 years. The quality of the wood was degraded due to weathering. Lastly, the 24-hour water soaking of the CCA-treated wood was not sufficient to soften the wood to produce high quality flakes.

The IB results are presented in **Figure 3**. The ANOVA did reveal statistical significance for dry and ODVPS IB, but the subsequent Dunnett tests did not indicate any statistical significance among the groups.

Group 2, which contained 75 percent CCA-treated wood, had the lowest IB strength. These results differ from previous studies that revealed similar trends for IB and bending strength (Boggio and Gertjejansen 1982, Hall et al. 1982, Jeihooni et al. 1994, Felton and DeGroot 1996, Vick et al. 1996, Munson and Kamdem 1998, Lebow and Gjovik 2000, Clausen et al. 2001). Also, there is a relationship between the surface and volume ratio of flakes. In short, a greater flake surface area needs more adhesive for equivalent IB values. 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, Vick et al. 1990, Vick and Christiansen 1993, Prasad et al. 1994) and CCA-treated wood has limited available lumen space, which adversely affects bonding on fiber surfaces (Vick and Kuster 1992, Felton and DeGroot 1996). The CCA treatment can also affect resin penetration and mobility, which will adversely affect panel bonding properties. Overall density and density distribution is another important effect factor on IB. Surprisingly and inexplicably, the IB strength with 100 percent CCA-treated flakes only had 5 percent reduction compared to those with 100 percent virgin flakes. It should be noted that the CCA furnish percents represent the amount of CCA-treated furnish and not the actual amount of CCA-treated wood due to the horizontal preservative gradient in the material. The entire guardrails were flaked, including the untreated inner core.

After the ODVPS procedure, MOR values decreased from 27 to 47 percent and MOE values decreased from 34 to 51 percent compared to dry specimens. The increasing trends can be visually observed in the bar graphs in **Figures 1** and **2**. 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-treated flakeboard had a slight

Table 3. — Average weight loss of two control groups (fresh southern pine and out-of-service guardrail) and flakeboard panels manufactured from five different ratios of recycled CCA-treated wood and virgin untreated southern pine wood after exposure to white rot (Trametes versicolor ATCC isolate 42462) for 16 weeks and brown rot (Gloeophyllum trabeum ATCC isolate 11539) for 8 weeks in a soil block test.

Group	Weight loss: White rot	Weight loss: Brown rot
	(%)	
1	6.8 (1.80)[a]	5.4 (1.11)
2	6.5 (0.68)	6.2 (2.05)
3	9.1 (1.07)	11.1 (3.01)
4	6.6 (0.69)	10.9 (6.99)
5	9.1 (1.29)	17.9 (9.38)
6[b]	12.0 (1.27)	44.7 (5.53)
7[b]	7.4 (0.87)	6.3 (1.14)

[a]Values in parentheses are standard deviations.
[b]Groups 6 and 7 are two reference groups, which were only introduced in decay-resistance tests.

variance, while the middle groups had the lower values (**Fig. 3**). The reductions of each group varied from 38 to 54 percent in terms of IB strength after ODVPS treatment. Overall, the ODVPS procedure significantly reduced the bending and IB strength of all panels.

Thickness swell, linear expansion, and water absorption results are listed in **Table 2**. Thickness swell was statistically significant according to the ANOVA test, but the Dunnett test did not reveal any significant differences among the groups. The ANOVA did not find any significant differences for linear expansion or water absorption. Therefore, the Dunnett test was not performed for these variables. In general, there was an increase of thickness swell as CCA-treated wood furnish content decreased. However, there were no discernible trends for linear expansion and water absorption with regards to CCA-treated wood furnish content. These results are partially consistent with a previous study (Munson and Kamdem 1998).

Decay resistance

In general, soil decay test results showed higher mean weight loss for both white-rot and brown-rot fungus as the flakeboard CCA-treated wood proportion diminished in the flakeboard (**Table 3**). Weight losses were less than 10 and 18 percent for Groups 1 to 5 subjected to white rot and brown rot, respectively (**Table 3**). These values are lower than the weight losses of untreated southern pine, which has 12.0 and 44.7 percent weight losses subjected to white rot and brown rot, respectively. Regarding the CCA-treated guardrail samples, the weight losses of Groups 1 and 2 had lower values for both brown rot and white rot. All the other groups had higher weight loss exposure to both brown rot and white rot, except Group 4 in the white-rot test. These results indicate that flakeboards fabricated from furnish with a high percentage of recycled CCA-treated flakes will tend to have lower mean weight losses than panels with a high percentage of untreated flakes in the furnish. However, it should be noted that all mean weight loss values were greater than 3 percent, which is commonly considered as the maximum weight loss allowed for acceptable decay protection. However, PF resin also 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 lower weight loss than control Group 7. Brown rot is the most destructive type of wood decay for softwood; therefore, it could explain the higher weight loss for test blocks subjected to brown rot (Schmidt et al. 1983). Furthermore, the soil block test offers a decay hazard more severe than would be encountered by flakeboard in most service situations. Previous results indicate that structural flakeboard should be well protected against decay to insure continued strength in a high decay hazard (Schmidt et al. 1983).

Differences in decay resistance among groups subjected to brown rot and white rot were tested and found to be significant. The Dunnett tests indicated that all the weight losses of flakeboard specimens were significantly lower than the fresh southern pine sapwood. Compared with CCA-treated guardrail samples (Group 7), the weight losses of Group 5 had significant higher value in the brown-rot test; whereas Groups 3 and 5 resulted in significantly lower decay resistance in the white-rot test.

The weight loss for Group 7 (the out-of-service CCA-treated southern pine guardrails) was 7.4 and 6.3 percent for white rot and brown rot, respectively. These numbers are higher than what would be expected for this material. However, it should be noted that the samples were taken near the untreated guardrail core and thus likely had a small preservative concentration. These samples were not chemically assayed.

Conclusions

It is clear that flakeboard made from recycled CCA-treated wood is technically feasible. As expected, most mechanical and physical properties had higher mean values as the percent of recycled treated wood in the furnish decreased. Decay resistance increased as the percentage 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 yield a lower mean weight loss for the soil block decay tests than panels with a higher percentage of untreated wood in the furnish.

More replicate panels and/or a bigger dimension of individual experimental panels are suggested for future experiments in order to minimize experimental error.

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