PARTICLEBOARD MADE FROM REMEDIATED CCA-TREATED WOOD: EVALUATION OF PANEL PROPERTIES

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ABSTRACT

CCA-treated southern yellow pine (SYP) chips were remediated utilizing acid extraction alone, and using acid extraction followed by bioleaching with the metal-tolerant bacterium *Bacillus licheniformis* CC01. "Cleaned" chips were used to make particleboard (PB) with 10 percent urea-formaldehyde (UF) resin, and the PB samples were evaluated for internal bond (IB), modulus of elasticity (MOE), modulus of rupture (MOR), thickness swell (TS), water absorption, and decay resistance. PB panels prepared from just acid-extracted chips and two-step remediated chips showed an average 22 and 28 percent reduction, respectively, in IB and 41 and 13 percent reduction, respectively, in MOR compared to values for PB prepared with untreated SYP chips. An 8 to 10 percent increase in MOE in the acid-extracted-chip PB and remediated-chip PB compared to the untreated-chip PB suggested densification of the fiber surface had occurred. Water absorption and TS after 24-hour submersion increased in PB prepared from acid-extracted and remediated chips (14% to 15%). Water absorption and TS were less (28% and 39%, respectively) for the acid-extracted-chip PB compared to the untreated-chip PB. Decay resistance was variable, with low weight losses (≤15%) for all PB samples exposed to *Postia placenta* and weight losses ranging from 11 to 25 percent for untreated and remediated PB exposed to *Gloeophyllum trabeum*. We conclude that reduced MOR and IB seen in remediated PB are the result of residual oxalic acid either embrittling the fiber or interfering with UF resin adhesion. Results of this study indicate that properties of remediated PB are diminished when CCA-treated chips are exposed to oxalic acid even at low acid concentrations for limited amounts of time.

Since the early 1970s, an estimated 60 billion board feet of wood treated with chromated copper arsenate (CCA) has been placed in service in the United States (7,13). There is increasing concern about the disposal problem this material is going to create as it nears the end of its expected service life. Novel approaches to remediate, recycle, or reuse this material are being developed (3,9-11,15-17). One approach, which utilizes a combination of acid extraction and bioremediation (bioleaching), substantially reduces the amounts of copper, chrotniutn, and arsenic in the wood (3-6,8).

The remediation method used in this study exposed chipped CCA-treated southern yellow pine (SYP) to oxalic acid extraction followed by incubation of the extracted wood chips in a nutrient culture medium inoculated with the metal-tolerant bacterium *Bacillus licheniformis* CC01. It has been shown that this two-step combination of acid extraction and bacterial exposure is more effective at releasing metals (70% to 100% of copper, chromium, and arsenic) from CCA-treated wood than either acid extraction alone or bacterial culture alone. However, the properties of particleboard (PB) prepared from CCA-treated chips remediated by this two-step method have not yet been investigated.

The objective of this study was to press SYP chips that had been remediated using the two-step method into PB panels and evaluate the properties of the panels compared to PB prepared with untreated SYP chips, CCA-treated SYP chips, and acid-extracted CCA-treated SYP chips.

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TABLE 1. -Atomic absorption analysis of CCA-treated. OA-extracted, and remediated southern yellow pine chips for copper; chromium, and arsenic content.

Chip type	CuO	CrO_3	As_2O_5
	(mg/g)		
CCA-treated[a]	3.1	7.8	3.4
OA-extracted[b]	1.5	7.8	1.4
Remediated[c]	0.9	1.5	0.0

[a] No remediation.
[b] Oxalic acid extraction of CCA-treated chips.
[c] Two-step remediation process (acid extraction followed by bacterial culture) of CCA-treated chips.

TABLE 2. - Particleboard properties.

Chip type	Thickness	MC[a]	SG[b]
	(mm(in.))	(%)	
Untreated	7.0(0.28)	9.3	0.7
CCA-treated	6.2(0.25)	8.6	0.8
OA-extracted[c]	6.2(0.25)	7.1	0.7
Remediated	6.9 (0.28)	8.4	0.8

[a] MC = moisture content (n = 8).
[b] SG = specific gravity (n = 8)
[c] n = 4.

MATERIALS AND METHODS

REMEDIATION OF CCA-TREATED WOOD

Two kilograms of chipped CCA-treated SYP (hammermilled to 6-16 mesh) were remediated using a combination of acid extraction and bacterial exposure to remove the copper, chromium, and arsenic as follows (3):

1. Eighteen-hour exposure to 18 L of 0.8 percent oxalic acid (Sigma Chemicals, St. Louis, Missouri) at 25°C (77°F) in 18-L polypropylene carboys.

2. Oxalic acid was siphoned off and 18-L nutrient broth (Difco, Detroit, Michigan), prepared according to manufacturer directions, was added and inoculated with 500 mL of an 18-hour culture of *Bacillus licheniformis* CC01 (5).

3. Carboys were incubated at 28°C (82°F), 100 rpm, for 10 days.

4. Spent medium was siphoned off, and remediated chips were collected on cheesecloth-covered screens and oven-dried at 60°C (140°F).

Three additional types of chips were used for comparison: 1) untreated SYP; 2) SYP commercially treated with CCA-type C to a retention of 6.4 kg/m^3 (0.4 pcf); and 3) CCA-treated SYP extracted with oxalic acid (OA). All chip types had been hammermilled and sorted to 6-16 mesh chip size.

ATOMIC ABSORPTION ANALYSIS

CCA-treated chips, OA-extracted chips, and remediated chips were analyzed for copper, chromium, and arsenic content by atomic absorption spectroscopy according to AWPA A11-93 (2) **(Table 1)** and results were reported as oxide for each metal.

PANEL FABRICATION

Panels were fabricated according to procedures outlined in the *Wood Handbook* (18). Two 40.64-cm- (16-in.-) square panels that were 0.64 cm (0.25 in.) thick, with an approximate specific gravity of 0.80, were formed per chip type. For each of four chip types (untreated SYP, remediated SYP, CCA-treated SYP, or OA-extracted CCA-treated SYP), 899 g of chips were blended with 10 percent urea formaldehyde (UF) resin (Southeastern Adhesives' 9-2035, Lenoir, North Carolina). The UF resin was applied in a rotating drum blender using an atomizing Binks spray gun. Panels were formed by hot-pressing for 5 minutes to an internal temperature of 121°C (250°F). Panels were trimmed to 40.64 by 40.64 cm (16 by 16 in.) and cut into specimens for testing according to ASTM standard D-1037-96a (1). Specimens were conditioned for 2 weeks at 65 percent relative humidity (RH) and 20°C (68°F) prior to testing.

STATIC BENDING

Conditioned samples, 7.62 by 20.32 cm (3 by 8 in.), two from each of two panels per chip type, were tested for modulus of elasticity (MOE) and modulus of rupture (MOR) per ASTM standard D 1037-96a (1). Moisture content, nominal thickness, and specific gravity were determined for these specimens **(Table 2).**

INTERNAL BOND

Tensile strength perpendicular to the surface was determined for four 5.08- by 5.08-cm- (2- by 2-in-) square *conditioned* specimens per panel evaluated or eight specimens per chip type according to ASTM standard D 1037-96a (1). A continuous load of 10 mm/min. was applied throughout the test.

THICKNESS SWELLING AND WATER ABSORPTION

Conditioned specimens, 15.24 by 15.24 cm (6 by 6 in.) (two per panel evaluated; four per chip treatment) were tested for 2- and 24-hour water absorption and thickness swelling (TS) according to ASTM standard D 1037-96a (1). Water absorbed from the increase in weight during submersion, and TS (as a percentage of the conditioned thickness) were calculated.

DECAY RESISTANCE

Decay resistance was determined by exposing six specimens, 1.59 by 2.22 by 0.64 cm (0.63 by 0.88 by 0.25 in.), for each PB panel evaluated to *Postia placenta* MAD 698 and *Gloeophyllum trabeum* MAD 617 in a soil block test for 12 weeks according to AWPA standard E10-91 (2).

RESULTS AND DISCUSSION

Remediated chips analyzed by atomic absorption analysis showed that the two-step remediation process of acid extraction followed by bacterial culture reduced residual copper, chromium, and arsenic in CCA chips treated to a retention of 6.4 kg/m^3 (0.4 pcf) by 70, 81, and 100 percent, respectively (3) **(Table 1).** The OA-extracted chips showed a decrease in copper and arsenic of 53 and 60 percent, respectively.

Results of the MOE, MOR, and IB analysis are shown in **Table 3.** The MOE for PB made with OA-extracted chips showed a 12 percent increase compared to PB made from untreated chips and a similar result was seen in PB made with remediated chips (8% increase) compared to PB made from

TABLE 3. – *Static bending (MOE, MOR), internal bond (IB), water absorption, and thickness swelling properties of particleboard samples.*

Chip type	MOE	MOR	IB	Water absorption 2hr.	Water absorption 24 hr.	Thickness swelling 2 hr.	Thickness swelling 24 hr.
	(N/mm^2)			(%)			
Untreated	145.0 (5.6)[a]	11.6 (0.7)	1.8 (0.2)	53.6 (3.3)	65.6 (3.0)	28.1 (0.9)	33.5 (1.8)
CCA-treated	255.0 (43.6)	11.8 (1.8)	1.7 (0.2)	19.1 (4.6)	42.5 (4.9)	11.8 (1.5)	25.7 (0.7)
OA-extracted	162.0 (57.6)	6.8 (2.7)	1.4 (0.3)	27.8 (4.7)	47.3 (0.2)	9.7 (0.9)	20.5 (0.2)
Remediated	157.0 (14.2)	10.1 (2.2)	1.3 (0.3)	49.0 (10.5)	74.5 (8.6)	26.3 (4.9)	38.6 (2.8)

[a] Numbers in parentheses represent standard deviations.

untreated chips. A 38 percent increase in MOE was seen in PB made with CCA-treated chips. The PB made with OA-extracted and remediated chips showed an MOR decrease of 41 and 13 percent, respectively, compared to PB made with retreated chips, and a 14 percent decrease compared to CCA-treated chips. The results suggest that the MOR reduction is due to residual acid either embrittling the fiber or interfering with UP adhesion.

Average IB values were higher than ANSI minimum values 0.45 N/mm^2 (65 psi) for M-2 grade medium-density PB (14). However, direct comparison of PB prepared from the various chip types showed differences between treatments. A 6 percent decrease in IB was observed in PB made with CCA-treated chips compared to PB made with untreated chips. All PB types showed decreases in IB compared to untreated PB. However, the decrease seen in the OA-extracted PB accounted for most of the total IB reduction seen in the remediated PB. The decrease in IB observed in remediated PB (28%) compared to untreated PB is most likely the result of residual OA interfering with UP resin adhesion or fiber embrittlement due to acid exposure in the initial remediation step. Increased MOE values combined with a decrease in MOR and IB for OA-extracted and remediated PB are indicative of chip densification.

UP-bonded wood composite products are not water resistant (12), so water-absorbing capacity and TS increases can be expected in untreated PB. The CCA-treated PB was the most resistant to water absorption and initial TS, but after 24-hour submersion, TS was 26 percent and water absorption was 43 percent for CCA-treated PB. The OA-extracted PB also displayed resistance to water absorption and TS even after 24 hours. The increase in TS between OA-extracted PB and the remediated PB, which was two-fold after 24-hour submersion, suggested that the additional treatment with bacterial culture increased water-absorbing capacity of the remediated fiber. The comparative differences, however, between the remediated PB and untreated PB were small; there was a 5 percent increase in TS and nearly 9 percent increase in water-absorbing capacity for the remediated PB compared to untreated PB. Overall, the remediated PB was comparable to untreated PB for TS and water absorption.

Decay resistance was ≤ 5 percent for all PB types exposed to *P. placenta* MAD 698 for 12 weeks in soil block culture (data not shown). This result was repeatable in subsequent studies (Kartal, Clausen, submitted). No weight loss was seen for CCA-treated PB exposed to *G. trabeum,* while untreated PB, OA-extracted PB, and remediated PB showed 11, 17, and 25 percent weight losses, respectively. There are no standardized test methods for evaluating decay resistance in composites. The variability seen in these results might suggest that 1) limiting access to the wood with resin may interfere with colonization of certain fungi, as noted by *P. placenta's* repeatable inability to decay untreated PB; and 2) residual metals in the remediated PB were in low enough quantities that they did not totally inhibit colonization, as noted by *G. trabeum's* ability to decay remediated PB to 25 percent weight loss. As a matter of fact, as more metals were removed from OA-extracted fiber with the bacteria, weight losses increased in blocks exposed to *G. trabarm.* In a subsequent study, *G. trabeum* equally decayed untreated PB (22%) and remediated PB (20%), and similar results were observed for OA-extracted PB (14%) (Kartal, Clausen, submitted).

CONCLUSIONS

PB panels made from the following types of SYP chips were evaluated for physical properties, strength properties, and resistance to biological decay: untreated, CCA-treated, OA-extracted, and remediated by a two-step method. Residual OA from acid extraction of CCA-treated SYP may have embrittled the fiber before panel fabrication or interfered with UP resin adhesion since most of the MOE increase, and the MOR and IB decrease, were noted in specimens after the acid extraction. There was little or no change in these properties between the OA treatment and specimens remediated with both OA extraction and bacterial culture. Results suggest that the bacterial culture increased the water-absorbing capacity of the remediated PB, since remediated PB (OA-extracted fiber subsequently exposed to *B. licheniformis)* showed a two-fold increase in water absorption and TS compared to OA-extracted PB. Resistance to biological decay varied: *P. placenta's* repeated inability to decay the untreated PB suggests that UP resin interferes with the ability of *P. placenta* to access the wood fiber in particleboard, while *G. trabeum* was able to cause 25 percent weight loss despite the presence of residual copper and chromium in the remediated PB. As increasing amounts of metals were removed from CCA-treated chips, weight losses increased in PB samples exposed to *G. trabeum.* Particleboard properties were somewhat diminished due to the remedial treatments, even though extraction time and OA concentration had been optimized (minimized) in a previous study to limit the exposure of the wood to the caustic effects of acid extraction (3).

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