Use of fire-impacted trees for oriented strandboards

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Abstract

This study evaluates the potential use of currently unexploited burnt timber from prescribed burns and wildfires for oriented strandboard (OSB). The research was performed in two phases: in Phase I, the effect of thermal exposure of timber on OSB properties was evaluated. Jack pine (*Pinus banksiana*) trees variously damaged by a moderately intense prescribed burn in a northern Wisconsin forest were selected. Four fire-damage levels of wood were defined and processed into series of single-layer OSB. The flakes used in Phase I had all char removed. Mechanical and physical properties were evaluated in accordance with ASTM D 1037. Results showed that OSB engineering performance of all four fire-damage levels were similar, and their mechanical properties met the CSA 0437 requirements. In Phase II, we assessed OSB properties from fire-killed, fire-affected and virgin red pine (*Pinus resinosa*) trees from a central Wisconsin forest exposed to an intense wildfire. The effect of various thermal exposures and varying amounts of char on OSB performance were evaluated. Phase II findings indicate that fire-damage level and bark amount had significant effects on the board properties. Addition of 20 percent charred bark had an adverse effect on bending strength; however, OSB mechanical properties still met the CSA requirements for all fire levels. Conversely, bark addition up to 20 percent was found to improve dimension stability of boards. This study suggests that burnt timber is a promising alternative bio-feedstock for commercial OSB production.

Oriented strand board (OSB) in combination with other structural wood-based composites such as plywood, provides 50 percent of the building materials for North American housing today. The OSB production in 2006 accounted for 60 percent of the North American panel market share (SBA 2006). While the high and increasing demand for OSB in the housing material market is encouraging, the long term resource availability for wood-based composites is now turning into a matter of concern for many mills.

At the same time, in the United States there is a considerable amount of wood potentially available as raw material for composites from recently fire-impacted sites. During 2006, more than 9.8 million acres were burnt by wildfire with a 10-year average of 6.4 million acres (NIFC 2006). Some forest stands are also burnt with prescribed fire as part of the forest management operations. Usually, this fire-affected material is considered unmerchantable because of concerns about wood quality, char inclusion, site damage or remote location.

The increase in wood demand, along with the general perception that wildfires create ecological disasters, have led to postfire removal of trees particularly in burned coniferous forests. In recent years, many North American forest industries have begun to harvest the burned stands soon after fire (Nappi et al. 2004). Watson and Potter (2004) reviewed the use of this fire-affected material in the pulp and paper industry. They noted that pulping of burned wood chips was first reported in

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1924. A pioneer work by Knapp (1912) indicated that conversion of fire-killed logs to lumber was a common practice in large mills on Puget Sound and the Columbia River. He found that bending properties of fire-killed and green Douglas-fir stringers and joists were practically equal when decayed material from fire affected lumber was rejected. Likewise, burnt timbers could also be used for wood composite products to offset demand for raw materials. Specifically, OSB production could employ this lower-value forest resource and simultaneously promote sustainable resource utilization. Using some portions of this burnt timber might also improve forest health and wildlife, watershed and ecological diversity. These burnt timber materials might also reduce needs for logging on less sustainable private, State or Federal lands. However, the feasibility of using fire-impacted timber for composites has yet to be considered in wood composites industries.

Impact of high temperature on wood properties

The effect of heat on wood properties has been extensively documented. Changes in physical and mechanical properties due to exposure to elevated temperature have been related to chemical modifications of wood components (Kolin and Danon 1998, Winandy and Rowell 2005). The degree of these changes depends on the magnitude and heating duration. According to LeVan and Winandy (1990) the thermal degradation of wood can be characterized as the compound effect of the thermal degradation of cellulose, hemicellulose, and lignin individually. Winandy and Lebow (2001) reported that wood strength reduction, in the earliest stages, is closely related to hemicellulose decrease, while further strength loss is a function of cellulose and lignin degradation.

Due to these significant changes in wood chemistry, it might be expected that intense fires such as wildfires could negatively affect important wood properties. However, it has been reported that wood damage due to fire exposure was limited to the outer part of trees (Watson and Potter 2004). Zicherman and Williamson (1981) examined the microstructure of wood subjected to fire and found three zones after exposure: an outer charred layer heavily distorted, an inner charred layer relatively undistorted, and a whole, nondegraded wood underlying the char. They also perceived a transition zone, extremely thin, between these last two layers which divided damaged and undamaged wood. A recent study by Bortoletto and Moreschi (2003) demonstrated that the heat released during a forest fire was not sufficient to degrade essential wood components such as hemicellulose and cellulose. They suggested that the insulation provided by the bark, specifically after its carbonization, as well as the short time of exposure to high temperatures, were the main factors that prevented wood degradation.

Use of bark in composite boards

The upward demand for wood based boards has driven many to consider other resources as raw material. Murphy et al. (2006) reported that demand for wood residue, such as bark, has increased, and over the past 15 years its end-uses had changed from fuel to pulp and fiber composites, among other uses. Significant research has established the feasibility of bark use in composite boards (Maloney 1973, Place and Maloney 1977, Muszynski and McNatt 1984). Normally, bark is employed to manufacture either homogeneous boards or in the core of a three-layered board. Regardless of the board type, bark inclusion in wood composites, in general, has a detrimental effect on a panel's strength due to the inherently weaker character of bark compared to wood (Wisherd and Wilson 1979). However, addition of small amounts of bark in particleboard could be beneficial. Dost (1971), who studied particleboard with 10, 20, and 30 percent bark addition, reported a decrease in water absorption of redwood particleboard with increasing bark level. Gertjejansen and Haygreen (1973) prepared aspen particleboards with flakes from butt, middle and top tree sections without removing the bark and found that inclusion of butt-log bark in the panels reduced their thickness swelling. A comprehensive work by Lehmann and Geimer (1974) showed that the strength (bending, internal bond) and stiffness of three-layer Douglas-fir particleboard decreased 20 to 30 percent with 25 percent bark addition in the furnish. Similarly, reduction in bending properties and internal bond strength was found by Wisherd and Wilson (1979) when 5, 10, and 20 percent of ponderosa pine bark was added to single-layer particleboards. In that study bark content did not affect the thickness swelling behavior of the panel. Suzuki et al. (1994) made single-layer particleboards from Japanese cedar wood with addition of bark in different percentages: 12.5, 25, 50, and 100. Based on bending strength results, they stated that 35 percent bark substitution was a reasonable limit for particleboard. Contradicting other findings mentioned above, Suzuki et al. (1994) also found that even at the lowest bark level substitution, board thickness swelling increased linearly with increasing bark content, and this was attributed to a decrease in bond quality. According to Blanchet et al. (2000) it is technically possible to make three-layer black spruce bark particleboard bonded with urea-formaldehyde resin and meet the American National Standard Institute (ANSI) indoor requirement. Nemli et al. (2004) made three-layer black locust particleboards with the addition of 6.25, 12.5, and 25 percent bark in the core layer of the board. They found a significant reduction in thickness swelling when 25 percent bark was included in the core layer. Recently, Xing et al. (2006) reported that medium density fiberboards (MDF) made with 40 percent bark showed 40 percent reduction in their bending properties, while their thickness swelling was not significantly affected.

Objective

The primary objective of this study was to identify the technical feasibility of using postburnt timber for wood-based composites. Specifically, we evaluated the effects of including charred timber and bark on the physical-mechanical properties and chemical composition of OSB. The research was conducted in two phases: the first concentrated on the effect on board properties of fire on bark with only limited effects on wood beneath the bark, while the second phase studied the effect of allowing various levels of burnt wood char to remain with the flakes and the additional effects of including some charred bark on OSB performance. This study was a cooperative effort between the Department of Bioproducts and Biosystems Engineering of the University of Minnesota and the USDA Forest Service, Forest Products Laboratory (FPL), Madison, Wisconsin.

Materials and methods

Selection and processing of logs

The material used in Phase I was jack pine (*Pinus banksiana*) from the Chequemegon-Nicolet National Forest near

Bayfield, Wisconsin, that has been exposed to a moderate-intensity prescribed fire. Within 3 weeks of the fire, six trees were selected for processing. Tree age was about 30 to 37 years old. The six trees were selected to contain various levels of charred bark. They were visually classified as follows: burnt level 1 (BL-1): unburnt; burnt level 2 (BL-2): lightly burnt outer bark; burnt level 3 (BL-3): moderately burnt outer bark; burnt level 4 (BL-4): severe-char damage to outer bark.

In Phase II, nine 55-year-old red pine (*Pinus resinosa*) trees from a central Wisconsin commercial forest were obtained that had each been variously damaged in a very intense wild fire that consumed about 3,400 acres (WDNR 2005). Within 2 months of the fire, the nine trees were cut. Tree selection was based on char thickness on the stem and the severity of foliage loss. Four categories of fire damage were defined: burnt level 1 (BL-1): No-char damage to outer bark and green needles; burnt level 2 (BL-2): low-char damage to outer bark and brown needles; burnt level 3 (BL-3): moderate-char damage to outer bark with brown needles; burnt level 4 (BL-4): severe-char damage to outer bark and no needles.

All trees were cut to 3.0-m-long logs, and each log was sectioned into two 1.5-m lengths. As a result, two logs from each tree were obtained: bottom section and top section, totalling 12 logs in phase I and 18 logs in phase II. A knife was used to remove all bark. Additionally, in Phase I study, any underlying charred wood material underneath the bark was also removed. Each bolt was cut into small blocks (150 by 76 by 25.4 mm) with moisture content (MC) values between 43 and 55 percent to produce strands of approximately 76-mm long, 25.4-mm wide, and 0.65-mm thick. The high MC contributed to create good quality strands during stranding, and the small variation of the MC among samples of different levels ensured a similar extent of fines generation to allow direct property comparisons of resulting panels. Strands from each bolt were kept separated and then dried to approximately 5 percent MC.

Panel manufacturing

Single-layer panel construction was used in both phase I and II studies. Roughly 2,800 g of wood strands per panel was employed to produce 690 kg m^{-3} density panels (560 by 560 by 12.7 mm). In addition, in phase II, bark was included in the furnish. We replaced 5, 10, and 20 percent of wood strands with the equivalent (ovendry (OD) weight) amount of bark. For each burnt level we employed its corresponding bark (e.g., panels labeled as “severe burnt” were made with strands and bark both from trees classified as severely burnt). The barks were individually hammermilled through a 3/8-inch screen and bundles of fibers and particulates were obtained. They were then dried to 6 to 8 percent MC. Two types of resin were used: liquid phenol-formaldehyde (PF) for phase I panels, and polymeric diphenylmethane diisocyante (pMDI) for panels made in phase II. Resins were applied to the strands/strands and bark in a rotating drum blender to a target content of 6 and 3.5 percent (OD wood weight basis) for PF and pMDI, respectively. Mat MC rose to approximately 7 to 8 percent in the resin-blending phase. The resinated strands were laid up by hand into a mat on a caul plate using a forming box. No strand alignment was attempted when the mat was formed. Mats were then hot-pressed using a pressing schedule for typical PF and pMDi resin cure time for a 12.7 mm panel: 480 to 520 seconds, including 30 seconds press closing time, and 30 seconds press opening time.

After the panels were pressed, they were hot-stacked for 24 hours, weighed and measured for SG determination. They were then cut up into various test specimens for mechanical, physical, and chemical composition determination. All specimens were conditioned at 65 percent relative humidity (RH) and 20 °C for at least 4 weeks before testing.

Experimental design

Phase I. — Phase I examined the effect of fire below the bark, for that reason flakes used in this phase had all char removed. The experimental design consisted of testing one factor, burning effect, at four levels: unburnt, lightly burnt outer bark, moderately burnt outer bark, and severe-char damage to outer bark (BL-1, BL-2, BL-3, and BL-4, respectively).

Phase II. — The research was expanded to a second phase to provide information on the effects of allowing various levels of burnt char to remain with the flakes. This attempt thus involved production of OSB from burnt timber and various loading percentages of charred bark. Although in commercial OSB production it is not a common practice to include bark in the furnish, we would like to study the possibility of extending the use of bark to increase biomass utilization. To realize this aim, a two-factor experiment was designed with four leveles for each factor: burning level (unburnt, lightly burnt outer bark, moderately burnt outer bark, and severe-char damage to outer bark) and bark content (0, 5, 10, and 20%). This resulted in a factorial design of 16 different treatments (Trt). It should be mentioned that for a specific burning level, both flakes and bark that were used in the panels came from the same log. For example, boards grouped under severe burnt level (BL-4) were made of flakes and different amounts of bark, both from severely burnt trees. In this manner, we tried to asses a similar extent of damage for the two factors involved in phase II.

Panel properties evaluation

Mechanical and physical tests were performed in accordance with ASTM Standard D 1037–00 (ASTM 2000). A replicate of 4 to 8 panels were produced from each of the 16 treatments. Two specimens per panel were prepared for modulus of rupture (MOR), modulus of elasticity (MOE), and internal bond strength (IB), and one specimen per board was tested for thickness swelling (TS) and water absorption (WA). In phase II, a specimen edge-sealed with a commercial sealant was included for TS and WA test to compare with the unsealed specimen. Vertical density profile (VDP) of IB specimens were measured prior to IB testing, on a QMS density profiler.

Chemical composition of boards, including lignin, glucan, and other sugars was evaluated using procedures developed by Davis (1998).

The mechanical and physical properties and the chemical composition of the boards in Phase I were compared ($p < 0.05$) for each burnt level using analysis of variance (ANOVA). In addition, chemical composition results were analyzed by Tukey simultaneous pairwise comparisons ($\alpha = 0.05$). In Phase II, the panel properties for each combination of burnt level and bark content were compared ($p < 0.05$) using a two-factor ANOVA. Tukey simultaneous pairwise comparisons ($\alpha = 0.05$) was then performed. In the case of TS and WA, where specimens were either edge-sealed or unsealed, the experimental design considered the edge sealed condition as block.

Results and discussion

Panel properties in Phase I study

Table 1 summarizes the mechanical and physical properties of jack pine OSB.

MOR mean values ranged between 34.5 to 38.9 MPa, and MOE from 4.7 to 5.3 GPa. IB results ranged from 0.72 to 0.84 MPa. No statistical differences among burnt levels were found for any of these mechanical properties.

Canadian standard 0437 (CSA 1993) was used for comparison of mechanical and physical properties. OSB mechanical properties (**Table 1**) were superior to those required by the CSA 0437 for boards classified as class R-1 ($\text{MOR}_{\text{randomly oriented}}$: 17.2 MPa, $\text{MOE}_{\text{randomly oriented}}$: 3.1 GPa, IB: 0.345 MPa). Avg. MOE and IB values were at least 100 percent higher compared to the standard, while MOE exceeded by 50 percent of the required value.

TS mean values varied from 32.6 to 36.8 percent while WA results from 58.2 to 65.4 percent. The lowest TS and WA mean values were found in panels from severely burnt trees (BL 4) although no statistical differences among burnt levels were found. None of the panels meet the required 15 percent maximum TS. A possible reason for these high TS values could be attributed to the fact that no wax was used during board manufacturing process. Mean panel SG was 0.64 to 0.65 (**Table 1**) and generally, the vertical density profile (VDP) of all types of boards has a U-shape (i.e., high face density and low core density).

Chemical composition of jack pine boards is presented in **Table 2**. Glucan and lignin are the two constituents whose amounts (in percentage) are significantly affected by burning, i.e., at the severe burnt level. Panels made with flakes from trees classified as severely burnt (BL-4) had a significantly lower glucan percent (mean value 37.9%) compared to those made with flakes from less severely burnt trees (i.e., BL-1, BL-2, or BL-3; mean value 39.4% to 39.5%). Given that wood strength is considered to be highly dependent on cellulose, reduction of cellulose fraction may explain the low MOR and MOE values found in BL-4 (**Table 1**), even though this strength and stiffness loss was not significant. Lignin percentage, on the other hand, significantly increased in BL- 4. The hydrophobic feature of lignin may be one attribute that is responsible for the TS and WA reduction of boards made with flakes from severely burnt trees (BL-4) though the reduction shown in **Table 1** is not statistically detected. None of the hemicelluloses components showed significant differences among burnt levels. These findings are in contrast with previous work which has demonstrated that hemicelluloses are more prone to thermal degradation at earlier temperatures than other chemical compounds, and they are also responsible in the earlier stages of wood strength loss (Winandy and Lebow 2001). However, it has to be stressed that the data presented herein derived from the chemical analysis of the composite board and not from the wood itself. The hemicellulose study of wood flakes from fire-impacted trees is currently underway and will be published in the future.

Panel properties in Phase II study

Mechanical and physical properties of red pine OSB are presented in **Table 3**. ANOVA results showed that bark content had a significant effect on the bending properties and on dimensional stability, while the burning effect was significant on board stiffness only. The two main factors are independent from each other because no interactions were significant for any property listed in **Tables 3** and **4**.

Bending properties

MOR mean values ranged from 34 to 47.5 MPa while MOE ranged from 4.6 to 6.2 GPa (**Table 3**). Panels made of flakes from trees classified as moderately burnt and without bark (Trt 9) showed the highest bending strength. Highest and near identical stiffness were found for panels made of flakes from lightly burnt trees and either 0 or 5 percent bark, and those made of flakes from moderately burnt trees and bark-free (Trt 5, Trt 6, and Trt 9). Least suitable bending properties were observed in panels made with severely burnt trees and 20 percent bark (Trt 16); still all of them exceeded MOR and MOE requirements of the CSA 0437.

Table 1. — Mechanical and physical properties of jack pine OSB in Phase I.[a]

BL[b]	MOR		MOE		IB		TS[c]		WA[c]		SG	
	(MPa)		(GPa)		(MPa)		------------(percent)----------					
1	35.6	(6.41)	5.09	(0.59)	0.72	(0.18)	36.81	(4.94)	63.18	(14.65)	0.65	(0.02)
2	38.2	(6.34)	5.27	(0.87)	0.83	(0.20)	35.89	(2.61)	65.35	(3.63)	0.65	(0.01)
3	38.9	(4.69)	5.07	(0.73)	0.75	(0.19)	35.12	(4.87)	60.90	(9.10)	0.64	(0.01)
4	34.5	(2.92)	4.72	(0.78)	0.84	(0.16)	32.56	(5.12)	58.17	(7.15)	0.65	(0.01)

[a] Numbers in parentheses are SDs.
[b] BL = burnt level. Assessment of fire-damage to standing tree prior to harvest: 1 = unburnt, 2 = lightly burnt outer bark, 3 = moderately burnt outer bark, 4 = severe-char damage to outer bark.
[c] After 24-hour water immersion.

Table 2. — Chemical composition (in weight percent) of jack pine OSB in Phase I.[a]

			Carbohydrates													
BL[b]	Klason lignin		Glucose		Arabinose		Galactose		Rhamnose		Xylose		Mannose		Others[c]	
	--------------------Total weight (percent)--------------------															
1	30.70	(0.58)	39.45	(0.47)	1.50	(0.04)	1.96	(0.29)	0.11	(0.01)	6.05	(0.34)	10.32	(0.81)	9.90	(0.21)
2	30.70	(0.74)	39.47	(0.76)	1.51	(0.07)	2.23	(0.35)	0.12	(0.01)	6.19	(0.14)	10.12	(0.57)	9.68	(0.43)
3	30.81	(0.75)	39.37	(0.78)	1.51	(0.04)	2.10	(0.38)	0.12	(0.01)	6.29	(0.38)	10.14	(0.25)	9.65	(0.26)
4	32.01	(0.92)*	37.91	(1.28)*	1.47	(0.03)	2.94	(1.01)	0.12	(0.01)	5.88	(0.34)	9.89	(0.32)	9.80	(0.37)

[a] Numbers in parentheses are SDs. Asterisks denote significant difference compared to unburnt OSB specimens: *$p = 0.05$.
[b] BL = burnt level. Assessment of fire damage to standing tree prior to harvest: 1 = unburnt, 2 = lightly burnt outer bark, 3 = moderately burnt outer bark, 4 = severe-char damage to outer bark.
[c] Include: Extractives, acetyls, uronic anhydrides, ash.

Table 3. — Mechanical properties of red pine OSB in Phase II.[a]

Trt[b]	BL[c]	Bark[d]	MOR		MOE		IB		SG	
		(percent)	(MPa)		(GPa)		(MPa)			
1	1	0	43.4	(5.68)	5.7	(0.37)	0.96	(0.28)	0.66	(0.03)
2	1	5	46.6	(10.09)	5.7	(0.85)	0.94	(0.24)	0.65	(0.01)
3	1	10	38.8	(4.95)	5.3	(0.55)	0.88	(0.35)	0.64	(0.01)
4	1	20	37.0	(6.75)*	5.0	(0.43)*	0.78	(0.17)	0.66	(0.01)
5	2	0	44.4	(8.74)	6.1	(0.69)	0.89	(0.25)	0.66	(0.01)
6	2	5	43.0	(5.42)	6.2	(0.60)	0.86	(0.32)	0.66	(0.01)
7	2	10	39.0	(6.12)	5.6	(0.59)	0.68	(0.23)	0.65	(0.03)
8	2	20	40.2	(7.51)	5.6	(0.95)	0.78	(0.32)	0.66	(0.01)
9	3	0	47.5	(7.46)	6.1	(0.85)	0.95	(0.16)	0.67	(0.01)
10	3	5	44.4	(6.96)	5.8	(0.72)	0.95	(0.30)	0.67	(0.01)
11	3	10	40.2	(6.99)	5.7	(0.79)	0.76	(0.28)	0.67	(0.02)
12	3	20	37.9	(5.98)*	5.5	(0.86)*	0.93	(0.13)	0.66	(0.02)
13	4	0	42.1	(5.48)	5.8	(0.56)	0.83	(0.23)	0.66	(0.02)
14	4	5	45.2	(5.97)	5.9	(0.97)	0.78	(0.17)	0.66	(0.01)
15	4	10	44.6	(6.35)	5.3	(0.55)	0.84	(0.37)	0.65	(0.02)
16	4	20	34.0	(11.22)**	4.6	(0.74)**	0.83	(0.17)	0.67	(0.01)

[a] Numbers in parentheses are SDs. Asterisks denote significant difference within burnt level in comparison to unburnt OSB specimens: *$p = 0.05$, **$p = 0.01$.

[b] Trt = Treatment. Combination of burnt level and bark content.

[c] BL = burnt level. Assessment of fire damage to standing tree prior to harvest: 1 = no-char damage to outer bark and green needles, 2 = low-char damage to outer bark and brown needles, 3 = moderate-char damage to outer bark with brown needles, 4 = severe-char damage to outer bark and no needles.

[d] Bark (by weight percent) included in OSB.

Effects of burning on MOE

Analysis of variance indicated that MOE was significantly affected by burning level in our phase II experiment. In-depth analysis of the data showed that this burning effect was restricted to few cases: boards made with flakes from severely burnt trees and 20 percent severely burnt bark (Trt 16, **Table 3**) yielded a significantly lower stiffness compared to those made of flakes from lightly burnt trees and 20 percent lightly burnt bark (Trt 8, **Table 3**). At this point, it should be remembered that the bark used for making boards grouped under severe burnt level (BL-4) was also severely burnt and that both flakes and bark came from the same log. This may explain the low stiffness found in Trt 16 boards. Additionally, MOE of panels without bark (Trt 1, Trt 5, Trt 9, and Trt 13) did not show statistical differences among the burning levels, leading to the conclusion that the board stiffness was not affected by burning level unless 20 percent of charred bark was included in the board.

Effects of bark content on MOR and MOE

The statistical analysis showed that bark content had a highly significant effect on the bending properties. In general, addition of 20 percent bark significantly decreased MOR regardless of burning level (**Table 3**). For example, adding 20 percent of moderately burnt bark to panels made with flakes from moderately burnt trees reduces their MOR about 20 percent. This was true in most burning levels with the exception of boards grouped under light burnt level (BL-2) where, even though there is no statistical difference, panels made of 20 percent bark showed a 10 percent strength reduction compared with those without bark.

A similar trend was observed in MOE, yet this bark effect was only observed in specimens grouped under unburnt level (BL-1) and severe burnt level (BL-4). Within these burning levels, panels made with 20 percent bark yielded a significantly lower MOE compared to boards without bark: specifically, a 12 to 20 percent reduction in stiffness was found. The different MOE behavior of the intermediate burning levels (BL-2 and BL-3) where no bark effect was observed may be explained by the fact that the amount of bark added to the panels, even at the highest 20 percent level, was still lower than in the previously reported thresholds at which the bending properties begin to decrease. In this regards, previous studies reported a 20 to 25 percent as a threshold (Lehmann and Geimer 1974, Nemli et al. 2004) while others established an even higher threshold value of 35 percent bark (Suzuki et al. 1994). The reduction in bending properties with bark addition could be attributed not only to bark's smaller particle size and lower strength compared to wood strands but also to the presence of bark fines generated in the hammermill process.

Internal bond (IB) strength

Average IB ranges from 0.68 to 0.96 MPa (**Table 3**). All boards exceeded the CSA 0437 standard (i.e., 0.345 MPa). Statistical analysis showed that none of the main factors (bark or burning level), nor their interaction had a significant effect on IB. This result suggests that addition of bark up to 20 percent did not affect panel IB strength. The unaltered IB strength could be explained by their manufacture as a single-layer OSB, with no bark concentrations in the core layer. In the case of concentrated bark present in the midplane thickness where IB failure most often occurred, the IB strength would be decreased by inferior resin performance due to bark characteristics such as density, particle geometry, and pH, as discussed by Wisherd and Wilson (1979).

Thickness swelling (TS) and water absorption (WA)

Analysis of variance established that specimens with edge seal significantly improved their dimensional stability compared to their matched unsealed (*p-value* < 0.001). In general, a minimum of 30 percent reduction in TS was found when edge-sealed. These results confirm the effectiveness of sealant application in reducing moisture penetration and TS. Data shown hereafter corresponds to results of specimens without edge-seal.

Average TS ranged from 15.8 to 18.9 percent while WA ranged from 25.3 to 33.0 percent, for unsealed specimens. None of the boards (without their edge sealed) complied with the 15 percent maximum required for the CSA 0437 standard. It is important to note that TS and WA of these boards could have been decreased with the addition of wax.

Compared to Phase I boards, the bark-free boards from Phase II has considerably lower TS and WA. This variation

Table 4. — Chemical composition (in weight percent) of red pine OSB in Phase II.[a]

					Carbohydrates													
Trt[b]	BL[c]	Bark[d]	Klason lignin		Glucose		Arabinose		Galactose		Rhamnose		Xylose		Mannose		Others[e]	
		(percent)	Total weight (percent)															
1	1	0	32.70	(0.66)	38.23	(0.81)	1.60	(0.16)	2.21	(0.16)	0.15	(0.01)	6.19	(0.58)	9.86	(0.33)	9.06	(1.08)
2	1	5	33.70	(1.13)	38.88	(0.93)	1.55	(0.02)	1.92	(0.13)	0.14	(0.02)	5.73	(0.01)	10.15	(0.21)	7.93	(0.11)
3	1	10	34.30	(0.44)	37.47	(0.73)	1.76	(0.22)	2.19	(0.33)	0.16	(0.03)	5.74	(0.30)	9.48	(0.38)	8.90	(0.66)
4	1	20	35.70	(1.48)*	37.07	(1.31)	1.82	(0.07)	1.90	(0.05)*	0.16	(0.02)	5.43	(0.16)*	9.48	(0.46)	8.44	(0.30)
5	2	0	32.50	(2.19)	38.96	(1.47)	1.49	(0.14)	1.86	(0.28)	0.13	(0.02)	6.05	(0.62)	10.27	(0.32)	8.74	(0.83)
6	2	5	33.60	(1.83)	38.61	(1.14)	1.54	(0.10)	1.74	(0.03)	0.13	(0.02)	6.01	(0.54)	10.06	(0.43)	8.13	(0.35)
7	2	10	35.50	(1.34)	37.35	(1.41)	1.57	(0.02)	1.62	(0.04)	0.12	(0.03)	5.25	(0.05)	10.06	(0.44)	8.53	(0.36)
8	2	20	35.10	(1.54)*	36.93	(1.00)*	1.84	(0.26)*	1.90	(0.16)***	0.17	(0.05)	5.71	(0.55)	9.44	(0.55)**	8.91	(0.59)
9	3	0	32.10	(0.88)	39.19	(0.88)	1.52	(0.17)	1.85	(0.30)	0.16	(0.05)	6.17	(0.61)	10.31	(0.35)	8.70	(0.76)
10	3	5	33.00	(1.56)	38.64	(1.03)	1.54	(0.10)	2.01	(0.34)	0.17	(0.03)	5.85	(0.69)	10.13	(0.33)	8.66	(0.89)
11	3	10	34.80	(1.52)	37.28	(1.52)	1.66	(0.11)	1.99	(0.38)	0.17	(0.03)	5.89	(0.74)	9.74	(0.19)	8.51	(0.55)
12	3	20	36.80	(2.40)***	36.04	(2.08)***	1.67	(0.01)***	2.14	(0.08)	0.17	(0.01)	5.27	(0.01)*	9.68	(0.74)*	8.23	(0.31)
13	4	0	32.10	(1.14)	39.31	(0.74)	1.45	(0.10)	1.91	(0.18)	0.13	(0.02)	6.06	(0.51)	10.72	(0.44)	8.32	(0.68)
14	4	5	32.40	(0.43)	39.06	(0.22)	1.48	(0.09)	2.07	(0.10)	0.14	(0.02)	5.73	(0.48)	10.49	(0.51)	8.63	(0.24)
15	4	10	33.30	(1.09)	38.48	(0.65)	1.65	(0.08)	1.99	(0.07)	0.16	(0.02)	5.85	(0.46)	10.31	(0.30)	8.26	(0.43)
16	4	20	35.80	(1.56)**	36.50	(1.30)**	1.72	(0.09)**	1.95	(0.06)**	0.15	(0.01)	5.26	(0.13)*	9.90	(0.42)*	8.63	(0.13)

[a] Numbers in parenthesis are SDs. Asterisks denote significant difference within burnt level in comparison to unburnt OSB specimens: *$p = 0.05$, **$p = 0.01$, and ***$p = 0.001$.

[b] Trt = Treatment. Combination of burnt level and bark content.

[c] BL = burnt level. Assessment of fire damage to standing tree prior to harvest: 1 = no-char damage to outer bark and green needles, 2 = low-char damage to outer bark and brown needles, 3 = moderate-char damage to outer bark with brown needles, 4 = severe-char damage to outer bark and no needles.

[d] Bark (by weight percent) included in OSB.

[e] Include: Extractives, acetyls, uronic anhydrides, ash.

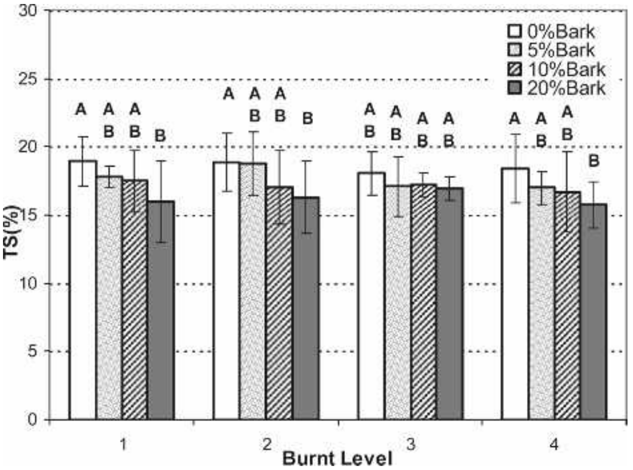

Figure 1. — Effect of bark content on TS of red pine OSB in Phase II. Burnt Level: assessment of fire damage to standing tree prior to harvest: 1 = no-char damage to outer bark and green needles, 2 = low-char damage to outer bark and brown needles, 3 = moderate-char damage to outer bark with brown needles, 4 = severe-char damage to outer bark and no needles; Bark included in OSB; error bars are SDs; same letter within a burnt level denotes statistically similar results (α = 0.05).

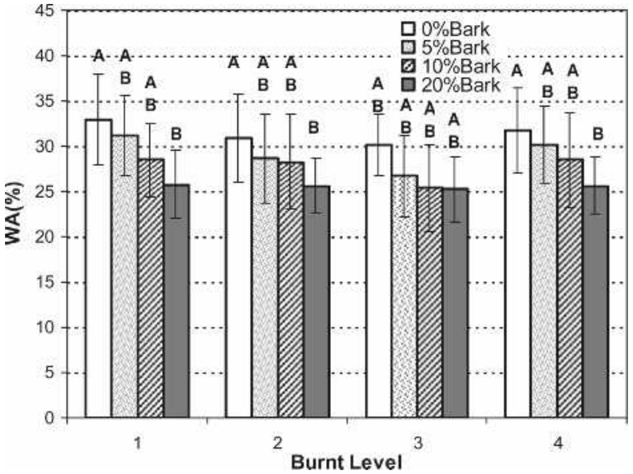

Figure 2. — Effect of bark content on WA of red pine OSB in Phase II. Burnt Level: assessment of fire damage to standing tree prior to harvest: 1 = no-char damage to outer bark and green needles, 2 = low-char damage to outer bark and brown needles, 3 = moderate-char damage to outer bark with brown needles, 4 = severe-char damage to outer bark and no needles; Bark included in OSB; error bars are SDs; same letter within a burnt level denotes statistically similar results (α = 0.05).

may be attributed to differences in the type and concentration of resin –PF in Phase I as opposed to pMDI in Phase II. Previous work showed that commercial OSB made with pMDI resin exhibited lower TS and WA values compared to those made with PF (Gu et al. 2005). It may also be attributed to the anatomical/chemical differences between jack and red pine. Finally, this difference in dimensional stability in both Phases of this study was presumably magnified by the absence of wax in the furnish.

Effects of bark content on dimensional stability

The favorable effect of bark on dimensional stability is readily seen in **Figures 1** and **2**. In general, addition of bark to the boards tends to decrease TS regardless of burning level (**Fig. 1**). Specifically, about 14 to 16 percent reduction was observed in panels made with 20 percent bark when compared to those without bark. This was true for boards in most burning levels with the exception of panels grouped under moderate burnt level (BL-3). Regarding WA, an increase in bark content resulted in a reduction in water absorption capacity (**Fig. 2**). A WA reduction of between 16 to 22 percent was observed in panels made with 20 percent bark compared with those without bark. The reduced permeability of water is thought to be a result of smaller interparticle voids caused by the fine bark particles compared to bark-free boards. This tendency to improve the dimensional stability of the boards as bark content increases is in good agreement with previous findings (Nemli et al. 2004).

Chemical composition

The chemical composition of red pine OSB is given in **Table 4**. Statistical analysis revealed that bark addition, but not burn level, had a significant effect on some chemical components of boards. No significant interaction between the main factors (burnt level and bark addition) was found.

Chemical analysis showed that addition of bark up to 20 percent to the panels tends to increase Klason lignin content, regardless of burning level (**Table 4**). In particular, boards made with 20 percent bark increased about 10 to 15 percent in their Klason lignin content when compared with those made of bark-free. The increased lignin content is a result of high content of lignin in barks (Harkin and Rowe 1971). Considering the hydrophobic characteristic of lignin, we can infer that the higher lignin content may be responsible for the TS and WA reduction found in boards with 20 percent bark. The TS and WA reduction could also be attributed to hydrophobic extractives from bark or carbonaceous compounds from char but their specific content cannot be inferred from the chemical analysis method that we used.

Regarding glucan content, chemical analysis showed that the presence of bark, which has lower cellulose content than wood (Harkin and Rowe 1971), decreases the cellulose content of the board. About a 9 percent reduction in glucan content in boards containing 20 percent bark was found with the exception of those panels grouped under BL-1 (unburnt) which showed a 3 percent decrease. The decrease in glucan content coincides with the drecrease in the MOE and MOR of the boards, agreeing with the common knowledge that glucan is mainly responsible for wood strength (Winandy and Lebow 2001).

Arabinose increased with increasing bark percent (**Table 4**), in accordance with observations that bark has much larger quantities of pectin substances with high proportion of arabinose (Larks 1991). When 20 percent of bark was added to the panels such increase ranged from 10 to 23 percent varying with burning level. Corresponding to the increase in arabinose, xylose and mannose decreased with the addition of bark. Approximately a 13 percent reduction in xylose was observed for boards with 20 percent of bark compared to bark-free boards in most burning levels, with the exception of BL-2. Mannose decreased approximately 7 percent with 20 percent bark addition. Although the depletion of arabinose in solid wood during decay and upon fire-retardant treatments was reported to correlate with bending strength reduction (Winandy and Rowell 2005), our OSB study showed a decrease in MOR with arabinose increase. This contradiction suggests that other significant factors influenced the properties of boards containing bark. In this regard, besides the influence of glucan discussed previously, another possible explanation to the poor contribution of bark to strength and stiffness is its lower content of fiber (Harkin and Rowe 1971). An additional reason could be the detrimental effect of the small particle size of bark, which has been discussed in the earlier section.

Conclusions

This study suggests that it is technically possible to use burnt timber as bio-feedstock for oriented strandboard. Phase I results indicated that the performance properties of jack pine OSB made with flakes from fire-exposed timber had similar properties of matched OSB made using nonexposed timber when charred wood was removed. Moreover, bending properties and internal bond strength of OSB met the CSA 0437 requirements. TS and WA of all jack pine boards were higher than the standard requirements. Chemical analysis indicated a reduction of glucan content in boards made with flakes from trees classified as severely burnt compared to those made of flakes from unburnt trees, however, this reduction did not cause significant strength and stiffness decrease. These findings proved that the uncharred wood underneath the burnt bark was virtually unaffected when processed from timber that was exposed to various levels of bark charring in a forest fire. This can be explained by the thermal insulating characteristic of wood.

In the second phase of our study, panels made of red pine flakes from burnt trees were found to have similar properties compared with those made of flakes from unburnt trees, if no bark was included in the boards. When bark was added to the panels, a negative trend in bending properties as the level of bark increased was apparent for all the burning levels. While addition of 20 percent bark had an adverse effect on the bending strength and stiffness, no effect was observed in the IB strength. Conversely, bark addition up to 20 percent was found to improve dimension stability of OSB. Further chemical analysis indicated that the composition of our phase II boards changed with the addition of 20 percent of bark. These chemical changes could partially explain the observed bending properties and dimensional stability behavior in our study.

This research supports the potential of utilizing currently underutilized burnt timber for wood based composites. This, in turn, can help to alleviate the harvesting pressure on other forestlands less sustainable for logging. Removing part of this burnt timber would also improve forest health and promote faster restoration of wildlife, watershed and ecological diversity, while at the same time reducing fire risk. Research currently undergoing in our lab is aimed to acquire a better understanding of mechanisms underlying these results through physico-mechanical and chemical tests of flakes and bark.

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