Preliminary Study on Flakeboard Panels Made from Aspen Slash Wood

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Abstract

The disposal of forest-thinning residue is one of the major problems for sustainable forest management. The purpose of this study was to investigate the technical possibility of utilizing aspen logging slash wood with a diameter ranging from 50 to 76 mm for flakeboard production. Influences of weight ratio between slash wood and commercial flakes on the selected mechanical and physical properties of panels were examined. The need of an extra debarking process for panel fabrication was also evaluated. The results indicated the modulus of elasticity (MOE), modulus of rupture (MOR), internal bonding, linear expansion (LE), thickness swelling (TS), and water adsorption of flakeboard made from aspen slash wood flakes were all comparable to those properties of panels made from aspen commercial flakes. The flake weight ratio between slash wood and commercial flakes had little impact on panel MOE, MOR, and LE. The statistical analysis (analysis of variance, $P < 0.05$) showed that the TS of panels made from 100 percent slash wood (22.8%) was significantly lower than the TS of panels made from a mixture of slash wood and commercial flakes or from 100 percent commercial flakes. The results indicate abundant slash wood, which is normally characterized by inferior mechanical and physical properties, could be a valuable resource for commercially available structural panel products.

Forest stands overstocked with small-diameter trees and understory are susceptible to attack by insects, disease, and catastrophic fire as a result of the heavy fuel load (Wolfe 2000). Removal of this material can reduce fire hazards, improve the composition of stand species and quality mix, provide healthier wildlife habitat, and protect watersheds. Much of this material is left on the ground or burned after thinning operations because of the high cost of removal. The materials from forest thinning include small-diameter logs, slash wood (limbs, tops, and foliage), and understory (SSU). Recent surveys showed that SSU in the 500 million acres of productive forest land in the United States was increasing at an average rate of 237 cubic feet every second (LeVan-Green and Livingston 2003). Gan and Smith (2006) estimated that annually recoverable SSU in the USA would be 36.2 million dry tons based on the 1997 Forest Inventory and Analysis data. The average cost for forest thinning was approximately US$70 per dry ton, which is usually more than the value of the thinned material, approximately US$25 to US$35 per dry ton, for the energy and chip markets (LeVan-Green and Livingston 2001). The economic analysis affirmed the necessity of developing value-added products from the SSU materials to compensate for the cost of forest thinning.

Considerable research has been dedicated to improving the economics of using SSU material. Gorman and Green (2000) as well as Lowell et al. (1997) found high-quality dimension lumber could be sawn from small-diameter trees and used for high-value, glued-laminated timber and trusses. Wolfe and Moseley (2000) tested several connection systems involving small-diameter logs and concluded that such logs could be used as structural elements with limited revisions to current specifications and design standards. Hunt and Winandy (2002) proposed small-diameter and crooked timber could be utilized to produce laminated structural lumber and a value-added, laminated I-beam by developing new sawing, laminating, and drying processes. Han et al. (2006) demonstrated the feasibility of manufacturing oriented strandboard (OSB) from small-diameter southern pine trees and found satisfactory strength and dimensional stability properties. Small-diameter Scots pine and birch trees were also found to be suitable for OSB production (Heräjärvi et al. 2004).

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Nearly all the research on value-added utilization of SSU materials has focused on small trees with a diameter of more than 102 mm. Even scrimber, a unique structural composite lumber product, needed to use logs in the 102- to 204-mm (4- to 8-in.)-diameter classification. We were unable to find published reports on the production of value-added engineered wood products from slash wood with a diameter of less than 76 mm (3 in.). There are several disadvantages to using such small-diameter woody biomass in traditional forest products. These include the difficulty in collecting and transporting a high-bulk-density material and the fact that traditional methods for removing bark will not work on small-diameter and irregularly shaped branches. This study, however, will explore the technical feasibility of manufacturing flakeboard panels using aspen slash wood with a diameter ranging from 50 to 76 mm (2 to 3 in.). The necessity of an extra debarking process for panel fabrication will be also evaluated.

Materials and Methods

Green aspen slash wood with high moisture content (about 95%) was obtained from a local plantation forest in northern Wisconsin. The materials were mainly composed of branches removed from the forest as part of silvicultural managements. Branches with a diameter of 50 to 76 mm (2 to 3 in.) were selected and cut into sections 136 mm (5.4 in.) in length (Fig. 1, left), which were stored in plastic bags to prevent moisture loss. The average specific density of the slash wood was 0.43, with a standard deviation (SD) of 0.02. The 136-mm-long branch segments were then forced through a laboratory disc-flaker, being sliced longitudinally. With the exception of one batch of slash pieces debarked in a rod mill to determine if debarking was of value in preparing slash-based OSB, the bark was left on the branch segments fed to the flaker. Figure 1 (right) shows the aspen flakes coming out of the flaker, with thicknesses ranging from 0.45 to 0.65 mm, widths from 16 mm to 55 mm, and lengths of approximately 136 mm. The fresh-cut flake had larger surface area and tended to curl tangentially because of the quick loss of moisture. This could potentially cause poor resin coverage. Therefore, the flakes were covered by aluminum screens immediately after flaking and were constrained by the screens through the entire drying process to keep them flat. The flakes were then dried in a laboratory tray dryer to a target moisture content of about 2.2 percent. Another interesting observation was that a large portion of bark was separated from the slash wood during the flaking process, and even more separated during the drying process because of different drying stresses. This could possibly eliminate the need for a debarking process before the normal flaking process. After drying, the flakes were screened with a 6.4-mm screen to remove fines. Some of the fines came from the bark, and the others were small flakes sliced from the edges. The fine content based on the total weight was 19 percent.

To evaluate the necessity for debarking, some aspen slash flakes were made from the sections that had been debarked in a rod mill developed in our laboratory. This method successfully removed most of the outer bark from the small slash wood and left a slightly damaged surface. The flakes went through the same drying and screening processes as those described above. Most fines were small flakes sliced from the edges and damaged surfaces, and the fine content of the flakes with bark removed was 12 percent. After screening, all flakes were conditioned and bagged. The final moisture content of the flakes before resination ranged from 4.5 to 5.5 percent.

To investigate the effect of slash wood flakes on board performance, the slash wood flakes were mixed with commercial aspen flakes at certain percentages when making flake panels. The commercial aspen flakes, with an average size of 0.7 mm in thickness, 8 to 36 mm in width, and 110 mm in length, were supplied from an OSB mill in Canada. The moisture content of the commercial flakes when received was between 5.0 and 6.5 percent. Six weight ratios of slash wood flakes to commercial ones were mixed at the following levels: 10:0 (100% slash wood flakes), 8:2 (80% slash wood flakes to 20% commercial flakes), 6:4 (60% slash wood flakes to 40% commercial flakes), 4:6 (40% slash wood flakes to 60% commercial flakes), 2:8 (20% slash wood flakes to 80% commercial flakes), and 0:10 (100% commercial flakes). In addition, a group of panels (DB group) were made with 100% debarked aspen slash wood flakes.

Regular water-soluble phenol-formaldehyde (PF) resin (51.5% solid content) for commercial OSB production was provided by Georgia-Pacific Resins, Inc. Flakes with different weight ratios were mixed and applied with PF resin in a rotary drum blender separately. The target resin content for all panels made in this study was 4 percent based on the ovendry weight of flakes. After resination, the flakes were randomly formed by hand in a forming box with dimensions of 559 by 559 mm (22 by 22 in.). The mat was then sent to a 91.4 by 91.4-cm Nordberg hot press with a

Figure 1.—Typical 136-mm-long aspen slash wood (left) and flakes (right) sliced from the slash wood.

PressMAN Press Control system (Alberta Research Center, Alberta, Canada) to hot press it into 15.9-mm-thick (⅝-in.-thick.) flakeboard. The platen temperature was 200°C, and a longer hot press time was used to ensure the full cure of resin (47 s at closing, 230 s at the target thickness, 90 s at opening). The target density for all flake panels was 0.672 g/cm^3. Three replicate boards were made for each level of flake weight ratio (FWR).

Modulus of elasticity (MOE), modulus of rupture (MOR), linear expansion (LE), thickness swelling (TS), water absorption (WA), and internal bonding strength (IB) were tested in accordance with the ASTM D1037-06a methods for evaluating properties of wood base fiber and particle panel material (ASTM International 2006). The specimen for static bending test is 76 mm (3 in.) in width and 356 mm (14 in.) in length. Static bending and IB tests were conducted on an MTS (Material Testing System 634.11F-24). The size of IB sample was 50.8 by 50.8 mm (2 by 2 in.). The TS and WA were measured after 152 by 152-mm (6 by 6-in.) samples were immersed in distilled water at the room temperature of 20°C for 24 hours. For each performance, six samples cut from the three replicate boards were tested, and their average and SD are presented for all values except IB, for which 12 samples from the three replicate boards were tested.

Results and Discussion

Figures 2 and 3 present the average MOE and MOR values and the corresponding SD for seven groups of panels with different FWR values. The average MOE values had a narrow range, from 4.11 to 4.81 GPa, for the seven FWR levels. Interestingly, the average MOE of panels made from 100 percent slash wood (10:0 in Fig. 2) was 4.17 GPa, which was slightly lower than both the average value of 4.67 GPa for panels made from 100 percent aspen commercial flakes (0:10) and the value of 4.41 GPa for panels made from 100 percent debarked slash wood (DB group). Although a vague trend of increasing MOE with increasing commercial flake contents could be observed, further statistical analysis showed no significant difference (analysis of variance [ANOVA], $P < 0.05$) among the average MOE values. In other words, the MOE of panels made from aspen slash wood flakes were equivalent or similar to the average stiffness value of panels made from commercial aspen flakes. The similar effect of FWR on the average MOR of panels was observed among the seven groups. The maximum average MOR value was 31.95 MPa when 60 percent commercial flakes were mixed with 40 percent slash wood flakes (4:6 ratio). The maximum average MOR was only slightly higher than the average MOR value of the panels made from 100 percent slash wood flakes. In addition, debarking before the flaking process did not seem to be effective for improving the panel strength; it only increased the average MOR from 28.75 to 30.65 MPa. Again, further statistical analysis (ANOVA, $P < 0.05$) confirmed that no significant difference in the average MOR values existed among the seven FWR groups. The results indicated that an extra debarking process was not necessary and that the existence of residual bark after screening would not result in a substantial decrease in board stiffness and strength, although it was noticed that the remaining bark in the board could present some negative effect on its appearance. These results contradict any expectation that panels made from a higher percentage of slash wood flakes would have lower mechanical performance because of the higher microfibril angle (MFA) in slash wood fibers (Reiterer et al. 1999). It is true that the stiffness of OSB largely depends on the mechanical properties of individual strands (Lee and Wu 2003, Cloutier et al. 2007). However, the effect of individual flakes on overall board mechanical properties could be diminished by strand compression ratio, random orientation of flakes, and panel vertical density profile. Cloutier et al. (2007) found that juvenile wood flakes had little impact on the MOR of OSB. A similar result was also observed in the production of structural composite panels with juvenile wood strands (Wasniewski 1989).

Figure 4 shows the effect of FWR on the IB of panels. Large variations in the average IB values were observed for all the FWR levels, and no obvious trend could be identified. It appears that the IB of panels made from 40 and 80 percent commercial wood flakes had higher average IB values than panels made from other FWR levels. However, the differences between these average IB values were not significant because of the large variations. It is expected that

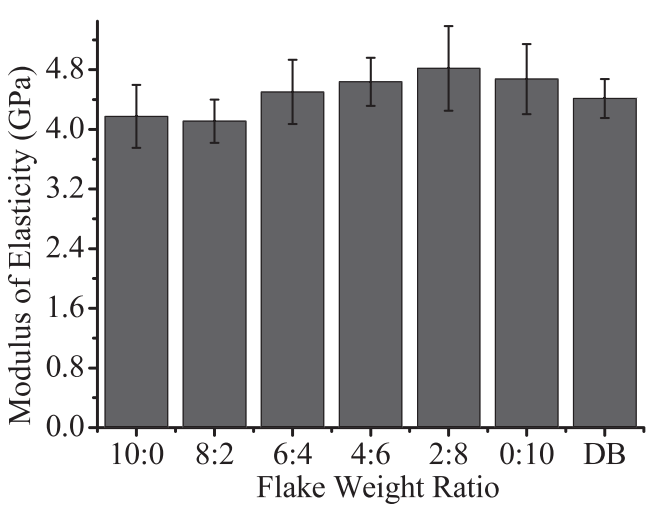

Figure 2.—Effect of flake weight ratio on flakeboard modulus of elasticity.

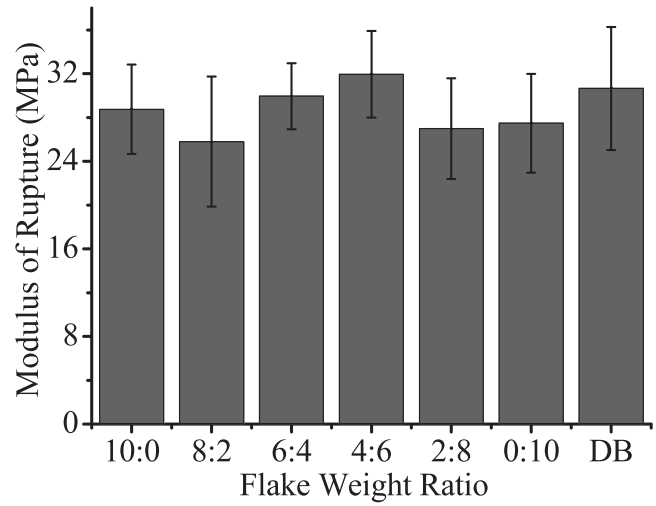

Figure 3.—Effect of flake weight ratio on flakeboard modulus of rupture.

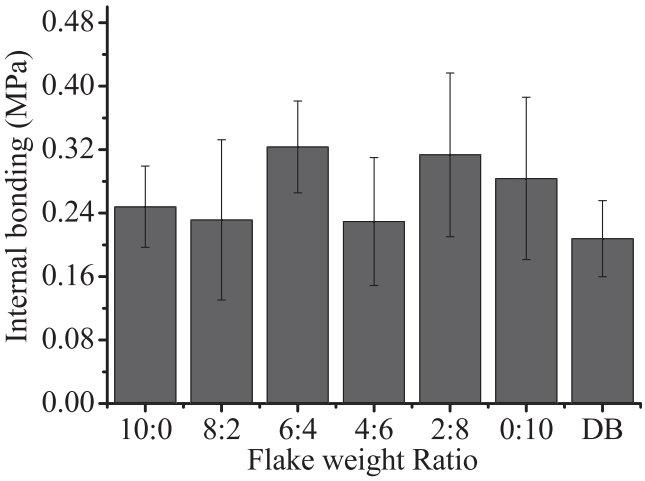

Figure 4.—Effect of flake weight ratio on flakeboard internal bonding strength.

more replicate samples might be useful to provide a definitive conclusion. In this study, the result based on the limited samples from three replicate panels indicates to us that the slash wood flakes with residual bark in the panel seem to have little effect on the internal resin bonding. One reasonable explanation is that the regular flaking and drying processes were effective at separating flakes from the bark and that the regular screen process was very successful at removing most of the bark.

LE is considered to be the most dominating parameter in qualifying the behavior of wood composite panels when exposed to moisture environments (Cai et al. 2004). Figure 5 shows the average LE coefficients of panels as a function of different FWR groups. The average LE values of panels made from all the FWR levels varied from 0.17 to 0.23 percent, meeting the minimum requirements of 0.30 percent for D-3 grade flooring products and building code grades prescribed in the American National Standard A208.1.2009 (American National Standards Institute 2009). The slash wood flakes in the panels were found to have little impact on the LE of our randomly oriented flakeboards. This observation coincided with the work done by Geimer et al. (1997). They found that the LE of random loblolly pine flakeboards made from juvenile wood was 0.32 percent (from ovendry to 90 percent relative humidity), which was only slightly higher than the value of 0.28 percent for mature wood under the same environmental conditions. For the oriented flakeboards, it is known that the flakes with higher S2 MFA (mostly for juvenile wood) could result in a higher LE. However, the random arrangement of slash flakes in this study might weaken and complicate this effect. Another reason might be the high compression ratio of 1.57 during consolidation of the low-density (0.43 g/cm^3) aspen flakes under hot pressing. The higher compression ratio could establish good flake-to-flake bonding during the mat densification process, which in turn would mask the effect of individual flakes (higher S2 MFA) on overall board mechanical properties. Further study with oriented flake forming technique is recommended to validate this observation.

The effect of FWR levels on the TS and the WA of different groups of panels are shown in Figures 6 and 7, respectively. The addition of commercial flakes had an obvious impact on panel TS and subtle influence on panel WA. On an average basis, the increase in commercial flake contents caused the increases of both panel TS and WA. However, the statistical analysis (ANOVA, $P < 0.05$) showed that only the TS of panels made from 100 percent slash wood (22.8%) was significantly lower than the TS of panels made from a mixture of slash wood and commercial flakes or from 100 percent commercial flakes. No significant differences in WA were found among the seven FWR groups. The significantly lower TS of panels made from 100 percent aspen slash wood flakes could be the result of their higher MFA and relatively smaller hygroscopic expansion in radial direction, which was in alignment with the panel thickness direction. The remaining bark, which usually does not absorb water, might have some impact on the TS and WA. Stefaniak (1981, 1985) found particleboard panels made from juvenile wood had lower thickness swell properties than those made from mature wood, and similar results have been reported for flakeboard by Geimer et al. (1997).

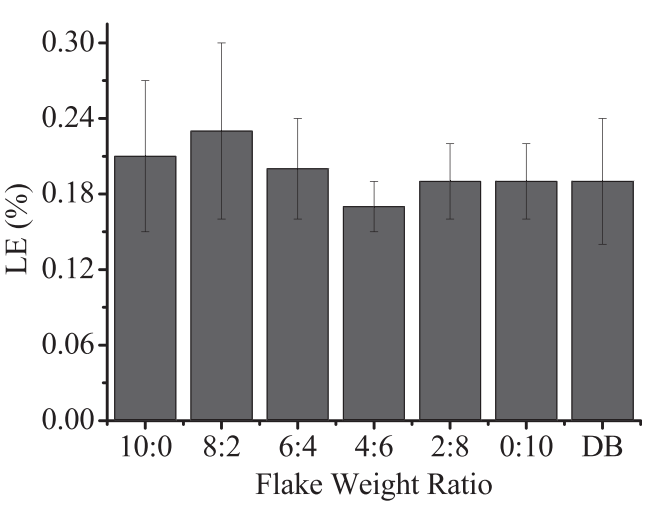

Figure 5.—Effect of flake weight ratio on flakeboard linear expansion (LE).

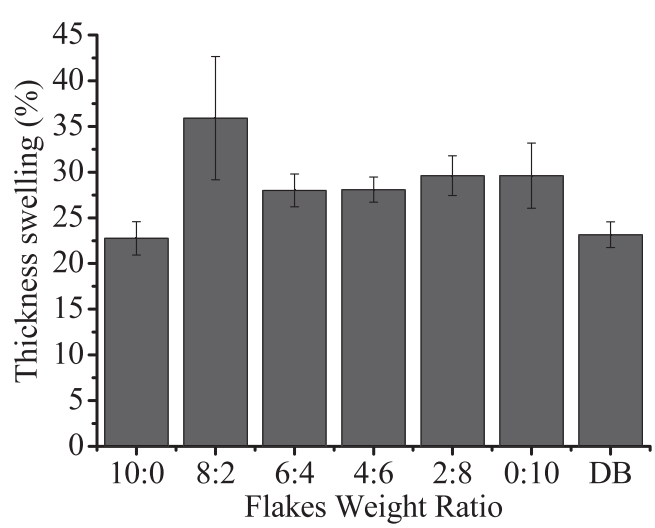

Figure 6.—Effect of flake weight ratio on flakeboard thickness swelling.

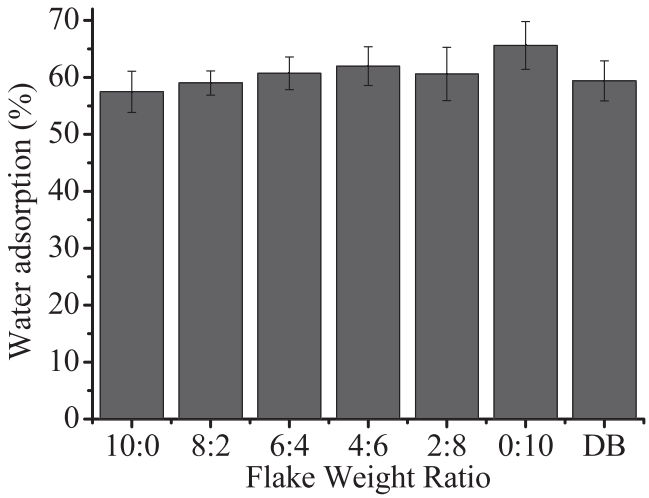

Figure 7.—Effect of flake weight ratio on flakeboard water adsorption.

Conclusions

Mechanical performance and selected physical properties of flakeboard panels made from aspen slash wood flakes and aspen commercial flakes were studied. The preliminary results show that the MOE, MOR, and LE of flakeboard panels made from aspen slash wood flakes were all comparable to those properties of panels made from aspen commercial flakes. The existence of barks did not cause a significant negative effect in the IB. Furthermore, the TS and WA might be improved slightly. It has been pointed out that the above results were based on the limited samples in the present study. Though extensive and systematic work is needed before more definitive conclusions can be made, our preliminary study at least indicates that slash wood, which is normally characterized by inferior mechanical and physical properties, could be a valuable resource for commercially available structural panel products without performance reduction. The value-added application of slash wood materials could potentially provide an economical solution for better forest management practice.

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