Abstract

Three-layer mixed comrind (CRD) and hardwood oriented strandboard (OSB) were manufactured using phenol-formaldehyde (PF) resin with comrind used in the core layer. The effects of comrind and wood (face and core materials) content on panel properties were examined. The values of flake percent alignment (PA) varied from 44 to 63 percent for different types of boards. Pure comrind boards had the highest PA value among all tested panels. The density profiles through panel thickness revealed that boards with 45 percent fines in the core layer had a considerable density gradient. Generally, density gradients increased with increased fines contents in the core layer. Linear expansion and thickness swelling were improved by using comrind to replace part of the wood material in the core layer. Internal bond strength showed little decrease as CRD content increased up to 22.5 percent for boards made of core material and CRD combination in the core layer. Bending properties of the boards with wood face material and CRD combination in the core layer reduced little when the CRD content was below 22.5 percent. At lower relative humidity levels, pure CRD OSB showed lower equilibrium moisture content values compared to wood OSB for both absorption and desorption. Nelson’s sorption model provided an excellent fit to the sorption data for both panel types.

Oriented strandboard (OSB) is one of the primary structural composites that are gaining increased use in both residential and commercial applications. It has been widely used as sheathing, flooring, and I-joist material in construction. With continuing production growth and decreasing quality wood supply, the cost of wood fibers used to manufacture OSB has more than doubled in the past 20 years (Spelter et al. 1997). Thus, development of alternative material for replacing wood fibers for OSB production is of great practical significance. Comrind (CRD), a useful product from sugarcane processing, is one of the potential raw materials for this purpose. CRD represents high-quality fibers in the outer layer of the cane stalk, which is approximately 50 percent of the dry weight of the stalk (Atchison and Lengel 1985, Paturau 1989).

In a previous study, anatomical features, and thermal, moisture sorption, and tensile strength properties of CRD flakes were investigated (Han and Wu 2003). The results showed that CRD has better or comparable properties compared with wood flakes. For example, tensile strength of CRD averaged 114 MPa, more than three times higher than that of willow flakes (31.5 MPa). It was concluded that CRD is a potential raw material for structural composite manufacturing. Various types of CRD composite panels including strandboard and waferboard were made in early studies (Atchison and Lengel 1985). The results showed that these rind-based structural boards had competitive strength properties with plywood. Previous work has indicated that even when standard particle-
board was made with this material in random formation, the resulting OSB board was superior to normal wood-based particleboard (Atchison and Lengel 1985). However, very little research work has been reported with CRD flakes used as raw materials for OSB.

The OSB process typically generates a proportion of small flakes (i.e., fines) that is separated from large flakes by screening during OSB manufacturing. Commercial OSB is manufactured with a considerable amount of fines placed in the core layer. The use of fines can help reduce raw material cost for OSB production. However, a large amount of fines in a given board leads to decreased mechanical properties and increased linear expansion properties along the cross-machine direction due to the random nature of the fines in the core layer. Previous studies indicated that increasing fines content reduced bending properties of OSB in a linear fashion (with evenly distributed fines and strands). For example, bending strength decreased about 28 and 40 percent as the loading levels of fines increased to 30 and 50 percent, respectively (Barnes 2002). The use of CRD with high strength and superior water-resistant properties to replace part of the fines in the core layer can help improve panel properties, especially along the cross-machine direction.

Generally, lignocellulosic materials from herbaceous plants have a slippery waxy layer on their outer surfaces, which has a significant impact on the bondability with phenol-formaldehyde (PF) and urea-formaldehyde (UF) resins (Han et al. 1999). Isocyanate as an alternative resin has been used to improve the properties of the boards made of agricultural fibers (Bowyer and Stockman 2001, Youngquist and Rowell 1989). However, the application of this resin is hindered by its high cost; hence, it is not commonly utilized, especially in developing countries. Recently, pretreatment of these herbaceous materials to remove waxes has been identified as a possible means to improve their bondability with UF adhesive (Han et al. 2001). CRD manufactured through a Tilby cane separation process can have the surface wax removed during cane processing (Tilby Systems Ltd. 2003). This provides the possibility of manufacturing high-performance OSB using CRD as the raw material and PF resin as the bonding agent at a competitive loading level.

The objective of this study was to develop comparative properties of the 3-layer mixed CRD and hardwood OSB bonded with PF resin. The effects of various CRD and wood combinations in the core layer on mechanical and physical properties were investigated.

**Materials and methods**

**Raw material preparation**

The CRD materials are the same as in the previous study (Han and Wu 2003). Comrind strands were prepared through the Tilby cane separation process (Atchison and Lengel 1985). The rind was about 45-cm in length and had been air-dried. The initial moisture content (MC) of the CRD was about 30 percent. The bundles of CRD were band-sawn into pieces of 11-cm in length. Two types of mixed hardwood flakes — large wood face material (WFM) and small wood core material (WCM) — were also prepared. All flakes were kiln-dried to about 3 percent MC prior to board fabrication. Commercial phenol-formaldehyde (PF) resin and wax with solid contents of 55 and 50 percent, respectively, were used.

**Panel manufacturing**

Three-layer OSB panels with controlled alignment level were manufactured with pure CRD, pure mixed hardwoods, and a mixture of both using PF resin in combination with wax. Two groups of panels were made in this study. **Table 1** shows the panel design. All 3-layer boards were made with 55 percent of WFM in the face layer and 45 percent WCM-CRD or WFM-CRD combinations in the core layer. The CRD was used in the core layer only except for the pure CRD boards, and the overall CRD content varied: 0, 13.5, 22.5, 33.75, or 100 percent. The PF resin and wax were added to the flakes with solid content levels of 4.5 and 1 percent, respectively, based on the oven-dried weight of the strands. Mats were formed using a specially designed forming box to control the strand alignment level. Boards were manufactured by hot-pressing at 190°C for 4 minutes with an additional 40 seconds press closing. The board dimension was 500 by 500 by 12 mm with a target density of 720 kg/m³. Besides 3-layer boards, single-layer uniform boards with 100 percent WCM (i.e., panel type A") were also made under the same conditions, for comparison. Two replicates were used for each condition, and a total of 20 boards were manufactured. The panels were trimmed and conditioned for 2 weeks under room conditions before testing.

**Panel testing and data analysis**

**Flake alignment level.** — Flake alignment angles were measured from board surfaces by randomly selecting 150 flakes on each side of the board. This was done by first taking a digital image of each of the two surfaces for a given board. A line parallel to the long dimension of each selected flake was drawn on the board surface using sigma scan software. The slope of the line was calculated and converted to the angle data. The alignment angle of each strand was measured from −90 to 90 degrees with 0 degree set as the principal machine direction.

Strand alignment was described by a percent alignment (PA) proposed by Geimer (1976). This measures the average angle deviation from a reference angle of 45 degrees to the principal alignment direction of the test board:

\[
P_A(\%) = \frac{45 - \theta}{45} \times 100
\]

where

\[
\theta = \frac{\sum \theta_i}{\text{total flake number}}
\]

where \( \theta \) = the average absolute alignment angle of each board; \( \theta_i \) = the measured angle over the range of −90 to 90 degrees.

The statistical cumulative distribution of strand alignment was done for each board based on a uniform interval of 10 degrees.

**Density profile.** — Density profile through the thickness of the specimen (50 by 50 mm) was evaluated using a Quintek Density Profile QDP-01X. The maximum, average, and minimum densities for each board were recorded. Six replicates were used, and the result was averaged for each group.

**Bending, IB, TS and LE.** — Unsanded boards were evaluated according to the ASTM Standard D 1037 (ASTM 1998). The tests included modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB), thickness swelling (TS), and linear expansion (LE).
Table 1. — Experimental design of pure wood, CRD, and mixed wood and CRD OSB.

<table>
<thead>
<tr>
<th>Material type</th>
<th>Panel type</th>
<th>Layering and material amount*</th>
<th>Overall CRD content</th>
<th>Overall WCM level</th>
<th>Overall WFM level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure wood</td>
<td>A</td>
<td>Face – WFM 55% Core – WCM 45%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A'</td>
<td>Face – WFM 55% Core – WCM 45%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A''</td>
<td>Face – WCM 55% Core – WCM 45%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixed wood-rind</td>
<td>B</td>
<td>Face – WFM 55% Core – CRD 13.5% &amp; WCM 31.5%</td>
<td>13.5</td>
<td>31.5</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>B'</td>
<td>Face – WFM 55% Core – CRD 13.5% &amp; WCM 31.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>Face – WFM 55% Core – CRD 22.5% &amp; WCM 22.5%</td>
<td>22.5</td>
<td>22.5</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>C'</td>
<td>Face – WFM 55% Core – CRD 22.5% &amp; WCM 22.5%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>Face – WFM 55% Core – CRD 33.75% &amp; WCM 11.25%</td>
<td>33.75</td>
<td>11.25</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>D'</td>
<td>Face – WFM 55% Core – CRD 33.75% &amp; WCM 11.25%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure CRD</td>
<td>E</td>
<td>Face – CRD 55% Core – CRD 45%</td>
<td>100</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

*WCM = wood core material; WFM = wood face material; and CRD = comrind. All panels were made with 55% and 45% of the materials in the face and core layers respectively.

Two specimens from each board, 343 by 74 by 12 mm, were cut along each of the two principal directions for static bending test (i.e., MOR and MOE). They were labeled according to board type and orientation (parallel or perpendicular). Tests in the dry condition were conducted in a three-point bending mode over an effective span of 288 mm at a loading speed of 5.88 mm/min. Six specimens of 50 by 50 by 12 mm for each condition were tested for IB strength at a testing speed of 0.98 mm/min.

The TS test was carried out on four specimens of 147 by 147 by 12 mm at each condition after being soaked in water for 24 hours at 20°C (ASTM 1998). Eight samples (four for parallel and four for perpendicular) of 288 by 74 by 12 mm were prepared for LE tests. Two holes 245 mm apart were drilled along the long dimension of each specimen. A small rivet (1.0 mm in diameter) with crossed hairline on the top, dipped in epoxy glue, was plugged into each of the two holes. All specimens were initially oven-dried for 24 hours, and then vacuum-pressure-soaked in the water at 20°C for 3 hours (1-hr vacuum at 686 mm Hg and 2 hr at 0.69 MPa pressure). LE was evaluated by measuring the reference distance between the two rivets before and after water soaking (Wu and Suchsland 1996).

Sorption isotherm. — Specimens for sorption tests, 20 by 20 by 12 mm, were prepared from mixed hardwoods and pure CRD OSB. For absorption tests, samples were conditioned over saturated salt solutions to reach equilibrium at a relative humidity (RH) of 32.5, 66, 76, 81, and 93 percent after oven-drying at 70°C for 2 days. The specimens for desorption tests were conditioned over distilled water to reach the fiber saturation state, and then tested under the same RH conditions as the absorption test. The initial weight, wet weight after conditioning, and oven-dry weight of all specimens were measured. The equilibrium moisture content (EMC) of each specimen was calculated based on the oven-dry weight.

Experimental data of EMC at various RH levels were fit to the sorption isotherm model proposed by Nelson (1983). The sorption isotherm is of the form:

\[
EMC = M_f \left( 1.0 - \frac{1}{A} \ln \left( \frac{RT}{W_w} \right) \ln \left( \frac{RH}{R} \right) \right) \tag{3}
\]

where \(W_w\) = molecular weight of water (18 l/mole); \(R = \) universal gas constant (1.9858 cal/mole/°K); \(T = \) absolute temperature (°K); \(A = \) natural logarithm of the Gibbs free energy per gram of sorbed water as RH approaches zero \((\Delta G_o, \text{ cal/g}), \text{i.e., } A = \ln(\Delta G_o)\); \(M_f = \) material constant that approximates the fiber saturation point for desorption (%).

A detailed description of the application of Nelson’s sorption model for wood-based materials was reported by Wu (1999).

Results and discussion

Flake alignment

Mean strand alignment levels of different board types are shown in Table 2. The values of PA for the tested boards varied from 44 to 63 percent. Pure CRD boards (panel type E) had the highest PA value among all tested panels. This is due to more regular strand shape and uniform width of CRD strands, which made it easy to control the strand orientation during the hand-forming process. The cumulative distributions of alignment angles for the boards with WCM-CRD and WFM-CRD combinations in the core layer are shown in Figure 1. Typical strand alignment distribution curves are illustrated for all evaluated panels. About 70 to 85 percent of the...
flakes for different panels were aligned within −30 to 30 degrees from the panel principal direction. Pure CRD OSB had superior alignment distribution compared with other mixed CRD and wood panels. This result agrees well with the PA value of CRD OSB. Different fines (i.e., WCM) and CRD contents did not show any effect on the cumulative strand alignment distributions.

**Mean density and density profile**

The mean densities for different board types are summarized in Table 2. Pure wood boards had the highest densities (at the target value), while pure CRD boards showed the lowest density values. For boards with WCM-CRD and WFM-CRD combinations in the core layer, board densities decreased with increase of CRD levels. This was due to different thickness springback of the boards after being released from hot-pressing. Wood strands in pure wood boards were bonded together more efficiently at the resin content level used (i.e., 4.5%) for PF resin, which caused small thickness springback of the boards after being released from hot-pressing. Wood strands in pure wood boards were bonded together more efficiently at the resin content level used (i.e., 4.5%) for PF resin, which caused small thickness springback of the boards after being released from hot-pressing.

Typical density profiles of the test panels are shown in Figure 2. In general, the density profiles of all tested boards had M-shapes, indicating regular density gradient through the panel thickness. The vertical density profiles (VDP) are formed from a combination of actions that occur both during consolidation, and also after the press has reached its final position (Wang and Winistorfer 2000). Previous studies have demonstrated that VDP has a significant effect on panel properties for wood-based panels (Xu and Winistorfer 1995, Xu 1999).

**Figure 2a** shows the effect of WCM and CRD combination in the core layer on VDP of the panel. Generally, density gradients in boards with 55 percent WFM in the face increased with increased WCM contents and decreased CRD contents in the core layer. Boards made of 45 percent WCM in the core layer and 55 percent WFM in the face layer had a considerable density gradient. This was due to the different degrees of strand uniformity of panel structures in the thickness direction for different types of boards. The board with 45 percent WFM had no large strands in the core layer, showing the largest strand shape differential between face and core layer. The density profiles also showed that boards made of pure WCM had the smallest density gradient. This was attributed to the more uniform mat structure along panel thickness direction.

**Figure 2b** illustrates the effect of WFM and CRD combination on the VDP of the panel. Similar to the WCM results, the density gradients decreased with increase of CRD contents. Boards made of pure wood large flakes had considerable density gradient compared to the boards with different CRD contents. Pure CRD boards showed a small density gradient. This was mainly caused by the considerable thickness springback of the CRD board after it was released from hot-pressing.

**Bending properties**

Bending properties (MOR/MOE) for boards with various CRD content levels are summarized in Table 2 and plotted in Figure 3. For both panel groups (i.e., WCM-CRD and WFM-

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**Table 2. — Panel properties of 3-layer mixed CRD and hardwood OSB.**

<table>
<thead>
<tr>
<th>Panel type</th>
<th>Density (kg/m³)</th>
<th>Thickness (mm)</th>
<th>PA (%)</th>
<th>MOR Par (MPa)</th>
<th>MOE Par (GPa)</th>
<th>IB Par (MPa)</th>
<th>LE Par (MPa)</th>
<th>WA Par (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>12.15</td>
<td>50.89</td>
<td>49.30</td>
<td>8.47</td>
<td>0.42</td>
<td>0.09</td>
<td>110.66</td>
<td>111.27</td>
</tr>
<tr>
<td>B</td>
<td>12.11</td>
<td>54.90</td>
<td>90.92</td>
<td>9.51</td>
<td>0.42</td>
<td>0.09</td>
<td>110.66</td>
<td>111.27</td>
</tr>
<tr>
<td>C</td>
<td>12.34</td>
<td>44.90</td>
<td>70.50</td>
<td>7.10</td>
<td>0.29</td>
<td>0.08</td>
<td>107.28</td>
<td>101.12</td>
</tr>
<tr>
<td>D</td>
<td>12.50</td>
<td>49.80</td>
<td>75.50</td>
<td>7.50</td>
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<td>0.08</td>
<td>107.28</td>
<td>101.12</td>
</tr>
<tr>
<td>A’</td>
<td>12.15</td>
<td>50.89</td>
<td>50.00</td>
<td>5.50</td>
<td>0.25</td>
<td>0.05</td>
<td>104.57</td>
<td>101.64</td>
</tr>
<tr>
<td>B’</td>
<td>12.12</td>
<td>54.90</td>
<td>80.00</td>
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<td>101.12</td>
</tr>
<tr>
<td>E</td>
<td>12.86</td>
<td>62.98</td>
<td>49.00</td>
<td>4.90</td>
<td>0.24</td>
<td>0.04</td>
<td>102.94</td>
<td>103.53</td>
</tr>
</tbody>
</table>

*PA represents the average value of percent alignment of the strands from both sides of the panel. Par = Parallel direction; Per = Perpendicular direction. Values in parentheses are standard deviations.

*TS is the value at 24.5 mm from the sample edge.*

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<th>Panel type</th>
<th>Density (kg/m³)</th>
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*PA represents the average value of percent alignment of the strands from both sides of the panel. Par = Parallel direction; Per = Perpendicular direction. Values in parentheses are standard deviations.

*TS is the value at 24.5 mm from the sample edge.*
CRD combinations in the core layer), there was a distinct difference for bending properties along parallel and perpendicular directions, indicating the effect of strand alignment and layering. For a given board type, MOR and MOE parallel values were higher than the perpendicular values due to the fact that 55 percent of the flakes were aligned in the parallel direction and 45 percent were aligned in the perpendicular direction. For pure wood boards, the property difference between parallel and perpendicular values of the boards with WCM in the core layer was larger than that of the boards with WFM in the core layer. This indicates that wood fines in the core layer resulted in poor balance of bending properties in the two directions. Using CRD to replace part of the wood fines can help reduce the difference of MOR and MOE in parallel and perpendicular directions, contributing a better property balance in these two directions.

For both types of boards, there was a decreasing trend of MOR and MOE with an increase in CRD contents. This decrease was more significant for the boards with WFM in the core layer. MOR and MOE decreased very little as CRD content increased up to 22.5 percent for the boards with WFM in the core layer. Also, the bending properties of mixed CRD and hardwood OSB were still comparable to commercial wood OSB, using 22.5 percent of CRD in the core layer for both types of boards. This is a promising result with PF-bonded mixed hardwoods and CRD OSB. Further increase of the CRD led to reduced bending properties. Pure CRD board had the lowest MOR and MOE values, but a better balance in parallel and perpendicular directions. The inferior bending properties of pure CRD boards were due to the poor bonding between CRD flakes caused by the outer waxy layer of CRD and the effect of large internal voids among the CRD strands. The use of thinner and better processed strands can help improve the properties.

**IB strength**

Figure 4 shows the IB strength of the panels as a function of CRD content. Using CRD to replace part of the wood material in the core layer lowered the IB strength of the panel. This was due to poor bonding between wood and CRD strands, and among the CRD strands themselves. However, for a CRD content level up to 22.5 percent (i.e., up to 50% CRD in the core layer), the mean IB values of the boards made of the wood core material and CRD strands combination were about 0.28 MPa. Further increase of the CRD content to 33.75 percent (i.e., 75% CRD and 25% wood core material in the core layer) lowered the mean IB value to about 0.19 MPa. For the

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**Figure 1.** — Cumulative distribution of flake alignment angles at various CRD content levels for 3-layer mixed hardwoods and CRD OSB: a) WCM-CRD combination in core layer; b) WFM-CRD combination in core layer. Refer to Table 1 for legend explanations.

**Figure 2.** — Density profile across panel thickness at various CRD content levels for 3-layer mixed hardwoods and CRD OSB: a) WCM-CRD combination in core layer; b) WFM-CRD combination in core layer. Refer to Table 1 for legend explanations.
boards with WFM (large flakes) and CRD combination in the core layer, the void in the mat could not be effectively filled. As a result, the IB value at a given CRD content level was smaller than the panels made with WCM in the core layer. Thus, small wood flakes can be used to fill the voids in the core layer, which improves IB performance. Pure CRD OSB had the lowest IB value of about 0.13 MPa, indicating poor bonding at the resin content level used. Thus, bonding pure CRD with PF resin at the low loading levels may pose some problems due to large voids and the surface waxy layer of the CRD. However, by using small wood flakes to fill the voids created by large CRD flakes and to bridge the bonding among CRD strands, IB strength can be considerably improved.

Linear expansion
Linear expansion data are shown in Table 2 and Figure 5. Similar to the results in MOR and MOE, there is a distinct difference in LE values along the parallel and perpendicular directions. The LE perpendicular values were higher than the LE parallel values. This is true especially for the boards with WCM-CRD combinations in the core layer. However, by using small wood flakes to fill the voids created by large CRD flakes and to bridge the bonding among CRD strands, IB strength can be considerably improved.

Thickness swelling
Figure 6 shows the effect of CRD content on the 24-hour water soaking TS of the panels. For pure wood boards, the TS value of boards made of WCM was about 10 percent higher than that of boards of WFM, indicating that using wood fines can cause TS problems for commercial OSB. The high TS of boards made of wood fines was due to the large surface area of small wood particles. Large wood strands had reduced surface area, thus led to less water absorption. However, the high price of large wood strands can increase production cost. Thus, using more large wood flakes is not a feasible way to lower TS.

The TS values dramatically decreased when using CRD to replace part of the wood material in the core layer. At the CRD loading level of 22.5 percent, the average TS values were reduced to around 24 and 29 percent for boards with WFM and WCM in the core layer, respectively. The TS values at the CRD level of 22.5 percent are still comparable to those of commercial OSB (Wu and Piao 1999). Thus, CRD can be used to improve the TS and water absorption properties of OSB. In addition, the TS of the board with WFM-CRD in the core layer was reduced considerably compared with the panels made with WCM and CRD in the core layer. This indicates that large wood strands in the core layer can help improve panel TS, and wood fines had an impact on panel dimensional stability.

The TS of pure CRD board was less than 10 percent, indicating the excellent dimensional stability of CRD boards. Similar to LE, the superior TS property of CRD boards was attributed to the inherent properties of CRD material. The lower TS value of CRD boards was also related to the small density gradient through panel thickness in these boards.
Sorption isotherm

Figure 7 shows typical sorption isotherms for mixed hard-woods and CRD OSB. At lower RH levels, CRD OSB showed lower EMC values compared to wood OSB for both absorption and desorption. This may be due to the higher wax content in the outer layer of CRD strands, which prevents moisture from transmitting into the panel through the CRD outer surface. CRD OSB showed higher EMC values than wood OSB, as RH was above 80 percent. This is probably due to the higher content of hemicellulose in CRD. A sorption hysteresis was observed for both tested materials. The symbols and lines in Figure 7 show the measured and predicted sorption values, respectively. It was found that Nelson’s sorption model reproduced accurately the experimental data for both wood and CRD OSB. The results of the regression analysis on sorption isotherms of the boards indicate that parameters $A$ and $M_V$ are different for the two types of panels. CRD boards had lower $A$ and higher $M_V$ values (absorption: $A = 3.94$ cal/g, $M_V = 28.52\%$; desorption: $A = 4.39$ cal/g, $M_V = 32.11\%$) than wood OSB (absorption: $A = 4.30$ cal/g, $M_V = 25.42\%$; desorption: $A = 4.62$ cal/g, $M_V = 31.13\%$). For both materials, the magnitude of $M_V$ was higher in desorption than in absorption at a given RH. These parameters can be used to predict EMC value of CRD and wood OSB at a given RH level.

Conclusions

In this study, the effects of sugarcane CRD and wood (face and core materials) contents on the properties of 3-layer mixed CRD and hardwood OSB were investigated. Pure CRD boards had a high flake alignment level compared to the boards with mixed structure of CRD and wood. The density profiles through panel thickness revealed that density gradient decreased with increasing CRD contents in the core layer. LE and TS were considerably improved by using CRD to replace part of the wood material in the core layer. As CRD content increased up to 22.5 percent (i.e., up to 50% CRD in core layer), bending properties reduced little for the board with face material in the core layer, and IB strength was still comparable to commercial OSB. These results indicate that CRD flakes can be successfully combined with wood flakes to produce 3-layer OSB with desired properties. Further work is needed on biological properties of the mixed CRD and hardwood OSB.
Figure 6. — TS at various CRD content levels for 3-layer mixed hardwoods and CRD OSB: a) WCM-CRD combination in core layer; b) WFM-CRD combination in core layer.

Figure 7. — Comparison of sorption isotherms for OSB: a) 3-layer mixed hardwoods; b) pure CRD. The symbols and lines indicate the measured and predicted sorption values, respectively.
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