Manufacturing Medium-Density Particleboards from Wood–Bark Mixture and Different Adhesive Systems*

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Abstract

The disposal problem of bark residues and the shortage of wood raw material supply in some regions make the use of bark an attractive option for the industry. In this study, medium-density particleboards were manufactured from mixed black spruce bark and spruce-pine-fir wood particles at a weight ratio of 50/50. Different adhesive systems were used as binders for the bark-based panels, including commercial phenol-formaldehyde (PF), urea-formaldehyde (UF), polymeric methylene diphenyl diisocyanate (pMDI) resins, and a laboratory-synthesized lignin-PF resin containing 30 wt% lignin substitution for phenol. The objective was to investigate the suitability of utilizing bark residues in the manufacture of particleboards for the floor underlayment (PBU) application. The resulting boards were evaluated according to the ANSI A208.1-2009 standard for internal bond (IB), modulus of rupture, modulus of elasticity, hardness, thickness swell, and linear expansion. The test results indicate that all panels made with these resin systems can meet the PBU requirements in terms of IB and hardness and that those bonded with 8 percent PF or 5 percent pMDI can meet all the requirements by the ANSI A208.1-2009 standard for the floor underlayment application in terms of the properties evaluated. Results of this study imply that it is feasible to use bark as a raw material to manufacture medium-density particleboard for the floor underlayment application.

Tree bark accounts for 9 to 24 percent of a log and is viewed as a low-value by-product of the wood products industry. Because of increasing environmental concerns and declining wood resources, more effort should be carried out to utilize bark as an alternative raw material for wood particleboard or fiberboard production. The high lignin and extractive contents make bark fiber not as fibrous as the woody parts of a tree, and the bark fibers are shorter than wood fibers (Harkin and Rowe 1971, Kiaei 2011).

In the past, two different approaches were used to manufacture bark panels. The first was to make panels without any adhesive based on self-bonding of bark particles by its natural high tannin and significant lignin contents. However, this technique required very high pressing temperature and long pressing time, impeding commercialization (Chow 1975, Gupta et al. 2011). In the second, synthetic adhesives were applied to bark particles to make bark particleboards and fiberboards.

Mechanical properties of bark panels differ, depending on the type of bark (Maloney 1973; Place and Maloney 1977; Xing et al. 2006a, 2007), but are always much lower than the corresponding wood particleboard or medium-density fiberboard (MDF) due to their inherent chemical composition. Thus, wood particles or fibers need to be used together

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with bark to improve the mechanical properties. Xing et al. (2006a) investigated the impact of the addition of bark fiber (0%, 20%, and 40%) with wood fiber on the physical and mechanical properties of MDF when urea-formaldehyde (UF) adhesive was applied at 12 percent content (solids on a dry wood and dry bark basis) to manufacture 12-mm-thick panels at a target density of 740 kg/m^3. The MDF panels containing 40 percent bark fiber were able to meet all the requirements of the ANSI A208.1-2009 (American National Standards Institute 2009) standard except for thickness swell for the floor underlayment applications (particleboards for the floor underlayment [PBU] grade). Xing et al. (2007) also manufactured wood fiber–bark fiber–wood fiber three-layer MDF (12 mm thick and 850 kg/m^3 target density). The variables used in panel manufacturing were face/core weight ratios (50/50, 40/60, and 30/70) and UF adhesive contents for core layer fibers (6%, 8%, and 10% on a solids basis). The UF adhesive content in the face layer was fixed at 12 percent (on a solids basis). The wood fiber–reinforced fiberboards showed modulus of rupture (MOR) values of 21.0 to 29.2 MPa, modulus of elasticity (MOE) values of 2,155 to 2,945 MPa, internal bond (IB) values of 0.37 to 0.58 MPa, and thickness swell (TS) values of 15.1 to 20.0 percent. The TS values still did not meet the ANSI standard (PBU grade).

Blanchet et al. (2000) produced wood–bark–wood three-layer particleboards by varying (1) wood particle content in the surface layer (0%, 25%, and 50%) and (2) UF adhesive content in the surface layer (12%, 14%, and 16% on a solids basis). An 8 percent UF adhesive (on a solids basis) was applied in the core layer. The test results showed that both mechanical properties and thickness swelling met the PBU grade for the panels with 25 or 50 percent wood particle content and 14 or 16 percent UF adhesive content in the surface layer. However, linear expansion was higher than that of the PBU grade for all the panels. Ngueho Yemele et al. (2008) prepared pure bark particleboard and wood–bark (50/50) particleboard and compared the resulting panels with 100 percent wood particleboard. The fine particles (1.5 to 2.6 mm) were used in the surface layer, and the others, including the medium size of 2.6 to 5.0 mm and coarse size of 5.0 to 7.0 mm, were used in the core layer. A phenol-formaldehyde (PF) adhesive was used in the core layers at 9, 7, and 6 percent (on a solids basis), respectively, for fine, medium, and coarse particles. A 12 percent PF adhesive was used in the surface layer. The resulting pure bark particleboards did not meet the requirements of the ANSI standard for the PBU grade (floor underlayment). The 50 percent bark particleboard showed higher mechanical strengths than the standard requirements but failed to meet the thickness swell requirement. Blanchet et al. (2008) manufactured the three-layer boards with 100 percent black spruce hammer-milled coarse particles in the core layer. Surface layers contained 50 percent wood particles–fibers and 50 percent black spruce bark particles. All boards were bonded with 8 percent of UF adhesive in the core layer and 14 percent of UF in the surface layer. All panels met the standard requirements except for linear expansion. In the work of Pedieu et al. (2009), the white birch inner bark particleboards were prepared with 22 or 25 percent wood fibers in the surface layer and 5, 9, or 13 percent wood fibers in the core layer. The UF adhesive content was 12 percent on a solids basis in both surface and core layers. Most of the panels met the 120 MDF-grade requirements.

From the previous studies, it seemed difficult to produce panels meeting the ANSI standard requirements for PBU grade with bark alone. With the combination of wood fiber or particles, the mechanical properties could exceed most PBU-grade requirements but not the dimensional stability requirements, especially that for linear expansion. The purpose of this project was to manufacture particleboard targeted for floor underlayment applications that could meet or exceed the PBU requirements by ANSI A208.1-2009, as shown in Table 1. The homogeneous particleboards were manufactured with a mixture of wood particles and black spruce bark particles at a weight ratio of 50/50. Different adhesive types were used as binders, including a commercial PF, UF, a polymeric methylene diphenyl diisocyanate (pMDI), and a laboratory-synthesized lignin-PF (LPF) resin with 30 percent phenol replaced with lignin. The target density and thickness of medium-density barkboard panels were 780 kg/m^3 (49 lb/ft^3) and 8 mm, respectively. The mechanical properties and dimensional stability of the panels were evaluated according to ANSI A.208.1-2009.

Materials and Methods

Preparation of bark and wood particles

Fresh black spruce bark (*Picea mariana*) was collected from a local sawmill in Quebec, Canada, kiln dried to 5 percent moisture content at 60°C, and then hammer milled into particles. Bark with particle sizes in a range of 0.3 to 1.5 mm was used for the board preparation. Fine spruce (*P. mariana*)–pine (*Pinus banksiana*)–fir (*Abies balsamea*) (SPF) softwood particles were obtained from a local particleboard mill. The particle size distribution of wood and bark particles was analyzed using the Tyler Standard Sieve Series, and the results are shown in Table 2. The bulk densities of wood particles and bark particles were 200 and 250 kg/m^3, respectively.

Adhesives

The LPF adhesive was synthesized in the laboratory with 33 percent phenol replaced with Kraft lignin, corresponding to about 18 percent (by weight) of the adhesive on a solids basis. The adhesive's solids content was about 40 to 42 wt%. The pH was between 10 and 11. The molar ratio of formaldehyde to phenol was between 2.0:1 and 2.5:1. Because of the low solids content of LPF adhesive, the mat moisture content of LPF5 resin (5% resin solids over ovendry wood weight) or LPF7 (7% resin solids over ovendry wood weight) was higher than 8.0 percent, which was considered the optimum mat moisture content for the PF and LPF particleboard. Thus, LPF adhesive used in this study was a mixture of liquid and powdered LPF. All adhesives used in this study are summarized in Table 3. An emulsion wax at a loading rate of 0.5 percent (solids on a dry wood–bark basis) was applied to improve the dimensional stability for all panels.

Particleboard preparation

The bark and wood particles were dried to below 2 percent moisture content before mixing and blending with an adhesive. The mat moisture ranged from 6.4 to 8.0 percent for all the panels. Mat moisture contents of pMDI3 and pMDI5 panels were adjusted to 6 percent by spraying the necessary amount of water on the particles before adhesive application. The emulsion wax and adhesive were

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Table 1.—Requirements of particleboard as floor underlayment (PBU grade).[a]

MOR, MPa (psi)	MOE, MPa (psi)	IB, MPa (psi)	Hardness, N (lb)	TS, mm (in.)	LE (%)
11.0 (1,595)	1,725 (250,200)	0.40 (58)	2,225 (500)	1.6 (0.063)	0.35

[a] PBU = particleboards for floor underlayment; MOR = modulus of rupture; MOE = modulus of elasticity; IB = internal bond; TS = thickness swell; LE = linear expansion.

premixed and then sprayed onto the particles using a nozzle system in a rotary blender. The other manufacturing parameters are given in Table 4.

Evaluation of barkboard

The panels were conditioned at a temperature of 20°C ± 3°C and a relative humidity of 65 ± 1 percent for 2 weeks before testing. The vertical density profiles (VDP) of panels were determined with a QMS X-ray density profiler (QDP-01X). Four static bending specimens (76 by 242 mm), two TS specimens (152 by 152 mm), two linear expansion (LE) specimens (76 by 305 mm), and 12 IB specimens (50 by 50 mm) were cut from each panel and all properties were evaluated according to ASTM D1037-06a (ASTM International 2010). LE testing was determined between 50 and 80 percent relative humidity. The ends of static bending specimens after testing were cut and glued together for hardness testing. Four hardness specimens (76 by 76 by 24 mm) were tested on both sides, and two penetrations were made on each side of a specimen.

Results and Discussion

Vertical density profile

The VDP of panels has a significant effect on the mechanical properties. As a general trend, higher surface layer density correlates with higher MOE and MOR, while higher core density correlates with higher IB strength of a panel (Chen et al. 2010). In this study, all the panels presented the typical M-shape VDP because a short closing time was used when pressing. Similar core density values were found for all the panels (810 to 830 kg/m^3; Fig. 1). With the exception of pMDI panels, higher adhesive content resulted in thinner and higher average density panels and a higher ratio of surface density to core density as well. The panels with 8 percent PF resin and 7 percent LPF resin showed an extremely high ratio of surface density to core density (1.06), followed by the panel with 10 percent UF resin (1.05). The other panels had similar ratios (1.01 to 1.02).

Internal bond

The minimum IB strength required by the ANSI A208.1 standard for the PBU-grade particleboard is 0.4 MPa. The IB values of panels with different types of adhesives and contents are shown in Figure 2. All panels complied with this requirement. The panels with UF adhesive showed the lowest IB value. The LPF resin applied at 5 percent (LPF5) performed similarly, as did UF resins (UF8 and UF10); however, increasing the resin loading level from 5 to 7 percent apparently improved LPF resin's performance in terms of increased IB strength. The panel bonded with LPF7 performed better than those with two UF resins and comparable to those with two PF resins (PF6 and PF8). The higher IB was obtained for panels bonded with pMDI resin. These results indicate that the pMDI resin results in the highest bonding strength among the four types of adhesives used in the manufacture of the wood composites. An increase of resin dosage by 2 percent improved IB strength for all panels made with PF, LPF, and UF resins. It is anticipated that the bond strength of barkboard can be further improved by increasing the resin content.

Table 2.—Size distribution of the wood and bark particles.

Size (mm)	Spruce-pine-fir wood (%)	Black spruce bark (%)
>1.4	4.4	0
0.84–1.40	26.5	29.2
0.50–0.84	35.7	52.1
0.30–0.50	18.5	16.2
<0.30	14.9	2.5

Table 3.—Adhesive type and typical properties.[a]

Adhesive type	Solids content (%)
Commercial PF resin	57
Laboratory-synthesized LPF resin	42
Commercial UF resin	68
pMDI resin	100

[a] PF = phenol-formaldehyde; LPF = lignin-PF; UF = urea-formaldehyde; pMDI = polymeric methylene diphenyl diisocyanate.

Table 4.—Panel manufacturing parameters.[a]

Panel dimension	8 by 580 by 530 mm
Board density	780 kg/m^3 (49 lb/ft^3)
Panel construction	Homogeneous
Raw material	Black spruce bark and SPF particles (50/50)
Mat moisture content	<8%
Adhesive loading rate	8% and 10% for UF (solids basis)
	6% and 8% for PF (solids basis)
	5% and 7% for LPF (solids basis)[b]
	3% and 5% for pMDI (solids basis)
E-wax content	0.5% (solids basis)
Pressing temperature	205°C for PF and LPF resins
	185°C for UF and pMDI resins
Total pressing time	170 s for PF and LPF resins
	140 s for UF and pMDI resins
Closing time	10 s for all resins
Replicates	2

[a] SPF = spruce-pine-fir; UF = urea-formaldehyde; PF = phenol-formaldehyde; LPF = lignin-PF; pMDI = polymeric methylene diphenyl diisocyanate.
[b] These actual resin contents were lower than the target values of 6 and 8 percent, respectively, owing to the miscalculating of resin solids content during panel manufacturing.

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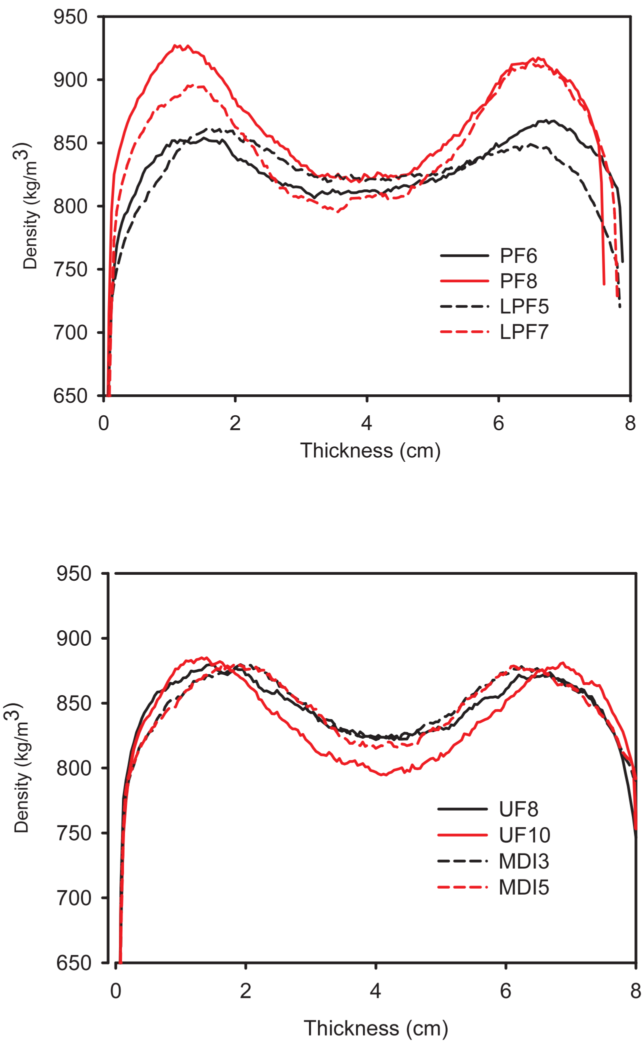

Figure 1.—Vertical density profile of panels. The number following each resin refers to the resin content on a solids basis. PF = phenol-formaldehyde; LPF = lignin-PF; UF = urea-formaldehyde; MDI = polymeric methylene diphenyl diisocyanate.

Static bending properties

The test results of MOR and MOE from static bending tests are shown in Figures 3 and 4, respectively. Among all the panels, PF8, pMDI3, and pMDI5 panels were found to exceed the PBU-grade standard requirement concerning MOR (11.0 MPa), with values of 12.1, 12.2, and 14.3 MPa, respectively. However, the MOE of the pMDI3 panel was a bit lower than the standard value (1,710 vs. 1,725 MPa). The MOEs of the PF8 and pMDI5 panels were 1,821 and 1,871 MPa, respectively. When comparing LPF7 with PF6, the former had much lower MOR and MOE, although they had very similar IB values. Thus, the panels bonded with LPF resin could not compete with those made with a regular PF. The bending properties of pMDI panels were a little higher than those of PF panels, although the IB of the pMDI panels was superior to that of the PF panels. This is probably due to the panel density, which is the main contributor to the bending properties of a composite panel (Xing et al. 2006b).

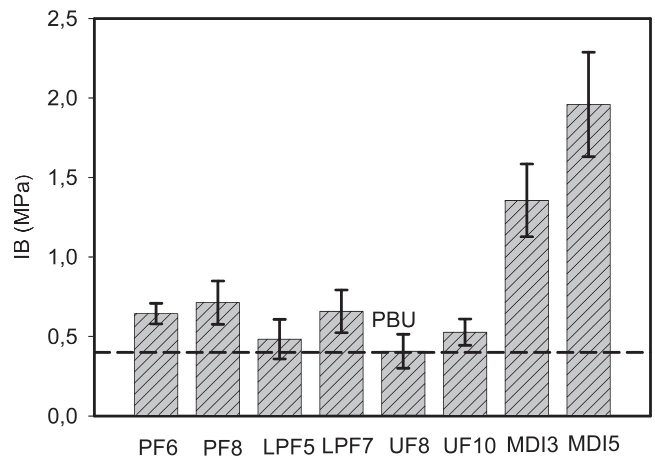

Figure 2.—Internal bond (IB) of the panels with different adhesives and contents. The number following each resin refers to the resin content on a solids basis. PBU = particleboards for floor underlayment; PF = phenol-formaldehyde; LPF = lignin-PF; UF = urea-formaldehyde; MDI = polymeric methylene diphenyl diisocyanate.

Hardness

The floor underlayment is required to provide the firmness necessary to resist compression from foot traffic and/or heavy furniture. As shown in Figure 5, all the panels satisfied the requirement of PBU grade regarding hardness (2,225 N). In general, pMDI and PF resins resulted in higher hardness of barkboard compared with LPF and UF resins. An increase in resin dosage by 2 percent resulted in improved hardness, as observed for PF- and UF-bonded panels.

Thickness swelling

Based on the standard requirement (Table 1), the qualified panels for PBU grade should have a maximum TS value lower than or equal to 20 percent, based on the panel

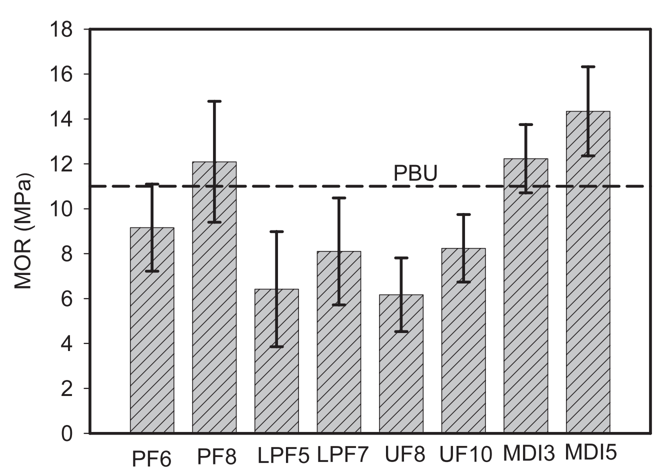

Figure 3.—Modulus of rupture (MOR) of panels with different adhesives and contents. The number following each resin refers to the resin content on a solids basis. PBU = particleboards for floor underlayment; PF = phenol-formaldehyde; LPF = lignin-PF; UF = urea-formaldehyde; MDI = polymeric methylene diphenyl diisocyanate.

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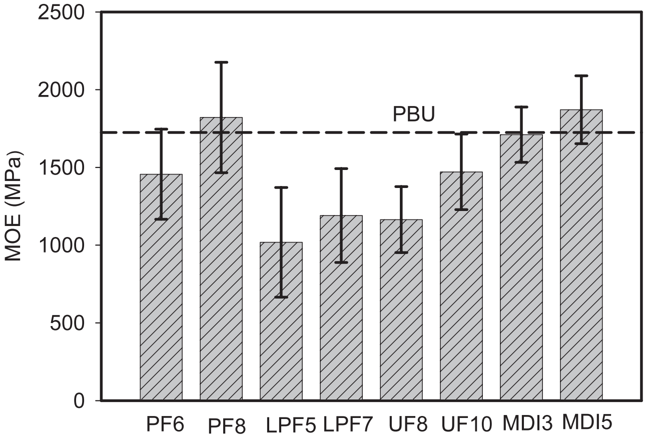

Figure 4.—Modulus of elasticity (MOE) of panels with different adhesives and contents. The number following each resin refers to the resin content on a solids basis. PBU = particleboards for floor underlayment; PF = phenol-formaldehyde; LPF = lignin-PF; UF = urea-formaldehyde; MDI = polymeric methylene diphenyl diisocyanate.

thickness of 8 mm. Figure 6 shows the TS after 24 hours in cold water (20°C). The panels with pMDI adhesive were the most water resistant among all the panels tested. The increase of pMDI content from 3 to 5 percent decreased the TS dramatically. The panels with PF adhesive also showed lower TS values. The increase of PF content from 6 to 8 percent had no influence on TS value. The panel with 7 percent LPF could satisfy the TS requirement as well. The panels bonded with 8 and 10 percent UF adhesive had much higher TS values than those of all other panels. These observations indicated that pMDI and PF resins produced more dimensionally stable barkboard than did LPF and UF resins.

Linear expansion

In the previous studies of barkboards, LE was the most difficult requirement to meet for the floor underlayment

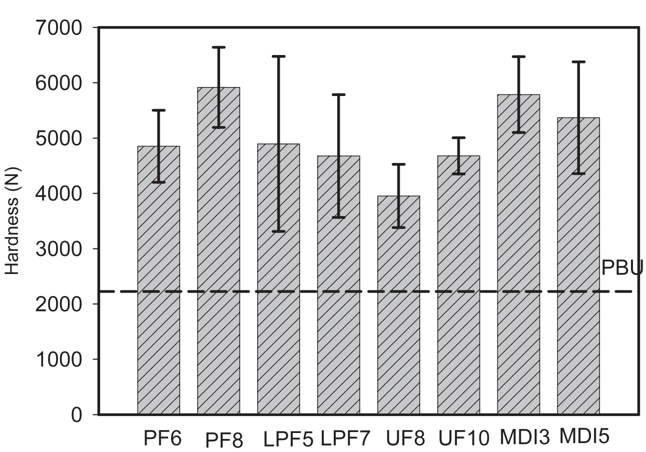

Figure 5.—Hardness of panels with different adhesives and contents. The number following each resin refers to the resin content on a solids basis. PBU = particleboards for floor underlayment; PF = phenol-formaldehyde; LPF = lignin-PF; UF = urea-formaldehyde; MDI = polymeric methylene diphenyl diisocyanate.

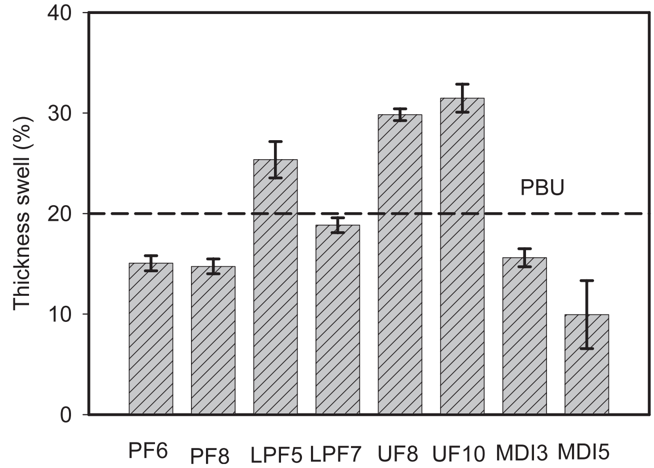

Figure 6.—Thickness swell of panels with different adhesives and contents. The number following each resin refers to the resin content on a solids basis. PBU = particleboards for floor underlayment; PF = phenol-formaldehyde; LPF = lignin-PF; UF = urea-formaldehyde; MDI = polymeric methylene diphenyl diisocyanate.

application (Blanchet et al. 2000, 2008; Ngueho Yemele et al. 2008; Pedieu et al. 2009). In this study, the panels manufactured with PF (6% and 8%) and pMDI (5%) were within the standard allowance (0.35%), as shown in Figure 7. As for the panel with 3 percent pMDI, its MOE was very close to the standard value (1,710 vs. 1,725 MPa); however, its LE was much higher than the standard value (0.43% vs. 0.35%). The panel bonded with LPF adhesive appeared to be superior to those bonded with UF adhesive but inferior to those with PF adhesive. These test results showed that pMDI and PF resins generally produced lowered LE panels compared with LPF and UF resins, but increasing the resin dosage reduced LE for all resin bonded panels, typically for that bonded with pMDI resin.

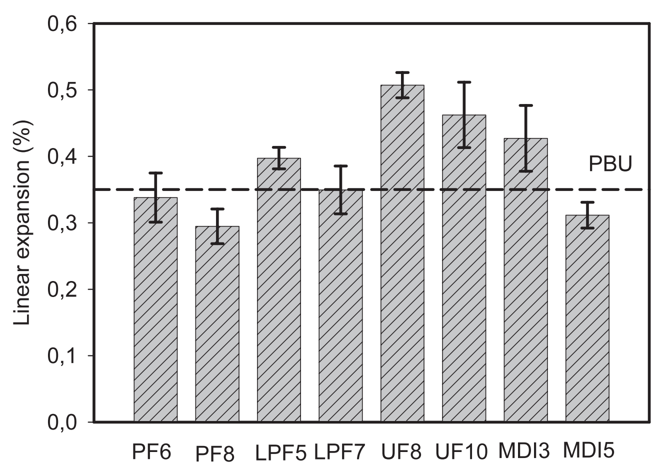

Figure 7.—Linear expansion of panels with different adhesives and contents. The number following each resin refers to the resin content on a solids basis. PBU = particleboards for floor underlayment; PF = phenol-formaldehyde; LPF = lignin-PF; UF = urea-formaldehyde; MDI = polymeric methylene diphenyl diisocyanate.

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Conclusions

In this study, black spruce bark and SPF softwood particles were mixed at a weight ratio of 50/50 and bonded with different adhesives to manufacture medium-density particleboards. The panels can meet all the requirements specified by ANSI A208.1-2009 for underlayment application when bonded with either 8 percent PF resin or 5 percent pMDI resin. All resin systems (PF, LPF, UF, and pMDI) can produce panels that meet the PBU requirements in terms of IB and hardness. This study has shown that it is feasible to use bark as a raw material to manufacture medium-density particleboard for the floor underlayment application if a proper adhesive resin system is applied at a suitable loading level.

Acknowledgments

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