

PROPERTIES OF BIRCH OUTER BARK PANELS REINFORCED WITH WOOD STRANDS IN THE SURFACE LAYERS

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The high demand of wood as a raw material can be expected to soon lead to a severe shortage, resulting in drastic competition between various mills. This competition will be worsened by a restriction of forest cuttings in Quebec. One of the solutions to this problem would be to develop a mixed panel in which the strands of core layer are substituted by outer bark particles, and in this particular case, by particles of white birch. This type of panel could be used as siding panels and for the fabrication of boxes, bins, and commercial shelving. The objective of the present research work concerns the design, the manufacture, and the evaluation of mechanical and physical properties of this type of panel. Two manufacturing factors were taken into account: the strands orientation in the face layers and the alkali treatment made on the bark particles used in the core layer. All produced mixed panels met and exceeded almost all CAN3-0437 R-1 and O-1 property requirements. The alkali treatment of bark particles did not improve the mechanical properties of manufactured panels. The statistical analysis method that was used made it possible to choose the panel with non-oriented wood strands in the surface layers and alkali treated bark particles in the core layer as the best by taking into account only the bending strengths in both major and side axes of a panel.

Keywords: Alkali treatment; Mechanical and physical properties; Mixed panels; Outer bark of white birch; Strands orientation

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INTRODUCTION

The quantity of bark produced in 2006 in Quebec province was *ca.* 3,260,000 tons. About 2.7% of these barks were those of white birch (*Betula papyrifera*) (DDIPF, 2006). With an increasing demand of wood composite products, wood will become less available (Sellers 2000). This shortage of wood can be expected to lead to a drastic competition among various mills that are using it as raw material. This competition will be worsened by restriction measures of forest cuttings imposed by the public authorities in Quebec following the conclusions of the Coulombe *et al.* (2004) report. The oriented strands board industry will be the most affected, because the production of strands requires wood coming from a quite straight trunk and without defects. One solution to this problem would be to develop a mixed panel in which the strands of the core layer are substituted by outer bark particles of white birch, which are obtained at a lower cost and are widely available.

Nowadays, many research projects are being carried out on value-added products such as barks or agricultural and recycled residues for the manufacture of panels (Sampathrajan *et al.* 1992; Kozłowski and Helwig 1998; Roffael *et al.* 2003). Boquillon *et al.* (2004) investigated the properties of wheat straw particleboards bonded with different types of resin. Interest has burgeoned in combining wood and other raw material into composite products that can utilize recycled materials (Youngquist *et al.* 1993, 1994, 1996).

If it is known that bark has some advantages over wood when used as a mulch or in other soil amelioration approaches (Allison 1965), it is not the same situation with respect to its utilization in particleboard manufacture because of poor mechanical properties of those particleboards (Blanchet *et al.* 2000; Villeneuve 2004). These types of panels are not yet fabricated industrially. In the case of this study the outer bark of white birch was used for panel manufacture at the laboratory scale. It is well known from the studies of Lundqvist and Back (1976) that birch outer bark is not a structural material like wood, because it has less than 4% cellulose. During the preliminary tests single layer panels with white birch outer bark particles were fabricated, but their mechanical properties were far below the requirements of the standard of M-1 grade panels for interior use. Only the thickness swelling after 24 hours water immersion of those panels was very good (less than 3%), confirming the hydrophobic characteristics of this bark. Lundqvist and Back (1976) suggested in their studies that, since it is impossible to produce panels with 100% birch outer bark particles meeting the standard of M-1 grade panels, therefore it is advisable to use them rather in the core of mixed panels with wood particles in the surface layers. From this suggestion, a 3-layer mixed panel was set up in the case of this study with outer bark particles of white birch in the core and strands of trembling aspen (*Populus tremuloides*) in the surface layers.

The general objective of the present research project was to find an alternative use of white birch bark that will be more profitable than to burn it for energy production. Thus, an investigation of the substitution effect of strands in the core layer of OSB panels by the outer bark particles of white birch on the physical and mechanical properties of produced panels was done. The investigations related especially to determine the following:

1. The effect of treatment of outer bark particles of white birch on the mechanical and physical properties of manufactured mixed panels;
2. The effect of strand orientation in the surface layers on the mechanical properties of produced mixed panels;
3. The best panel design, determined with the help of a factorial analysis carried out in a randomized complete block experimental design.

EXPERIMENTAL

Materials

The barks were obtained from the sawmill of Thomas Louis Tremblay Inc. of Ste-Monique, located in the north of Quebec (Canada). The strands were from the OSB mill Chambord in Chambord Lac St-Jean (Canada). The black spruce fibres used were obtained from the MDF mill La-Baie of Ville La-Baie (Canada).

Methods

The proportion of sapwood in those barks was approximately 8% of their oven-dried weight. They were dried at room temperature for ten days to 9% moisture content and then reduced to chips with the help of a hammer mill (Jeffrey) and refiner (Pallmann). The inner bark was separated from the outer bark by screening. The dust was eliminated by the means of a 0.25 mm mesh vibrating horizontal screen. The sizes of outer bark particles finally obtained were between 0.25 mm and 1 mm. They were dried to 3% moisture content in a laboratory-type dryer. In the same way, wood strands and wood fibres were also dried to 3% moisture content. The separated inner bark particles were used to manufacture a mixed particleboard reinforced with wood fibres (Pedieu *et al.* 2009).

NaOH treatment of outer bark particles of white birch

NaOH water solution was used to remove the wax from bark particles surface and to alter suberin layers that cover this surface and behave like Teflon. This was done to facilitate their wettability during the blending stage and to improve the interfacial bond of PF resin. During the preliminary tests, a 1% NaOH solution was used for the treatment with the following ratio: 2 g of dry bark in 100 ml of 1% NaOH solution. This mixture was heated for 30 minutes as required by the standard. But this approach was judged to be a failure because bark particles used were totally dissolved. An alternative solution was to decrease the concentration of NaOH in the solution and to carry out an empirical cold-temperature treatment. Thus, 6 kg of bark particles were weighed and put in a rotary mixer. Then 200 g of pure NaOH prior was dissolved in one litre water and used to spray the bark particles. Next, the mixer was left in rotation for 10 minutes for the best impregnation of bark particles. Finally they were removed from the mixer and dried initially at room temperature for three days and thereafter in a laboratory-type dryer until 2% moisture content was reached before their use in the manufacture of panels.

The alkali treatment done on bark particles to be used in their core layers will help protect them from some fungal degradation because of the high pH value generated and the presence of non-condensed phenol from the PF resin used to bond them (Willeitner 1956; Gersonde and Deppe 1968; Schmidt *et al.* 1978).

Addition of wood fibres to bark particles

The cellulose content of outer bark of white birch being very low (less than 4%), it is not a structure material such as wood. The result of preliminary tests showed that its use in the panel manufacture leads to a decrease of bending strength. Therefore, an addition of wood fibres to these bark particles to be used in the core layer of mixed panel

could help improve its bending strength. A quantity of ten percent (by weight) wood fibres was added to bark particles.

Experimental design

A factorial experimental design with two factors was used in a complete block design (CBD). The first factor was the type of material used in the core layer. It was a qualitative factor with three levels: 1) untreated outer bark particles of white birch, 2) alkaline treated outer bark particle of white birch, and 3) a mixture of untreated outer bark particles of white birch and a small percentage of wood fibres. The second factor was the orientation of strands in the surface layers of panel. This factor was also qualitative but rather with two levels: 1) oriented strands, and 2) non-oriented (randomly oriented) strands. Blocking was used to prevent nuisance factor from known and controllable sources of variability (Montgomery 1997). The total panel types in each block resulted from the multiplication of both factor levels, that is to say $2 \times 3 = 6$ panel types. Each panel considered as an experimental unit was replicated three times to give a total of 18 panels. The identification of six panel types is presented in Table 1.

Table 1 Description of Panels' Types

#	Types	Description
1	P_o	Mixed panel with oriented wood strands in the surface layers and untreated outer bark particles of white birch in the core layer
2	P_{o-f}	Mixed panel with oriented wood strands in the surface layers and a mixture of untreated outer bark particles of white birch (90% by weight) and wood fibres (10% by weight) in the core layer
3	P_{o-s}	Mixed panel with oriented wood strands in the surface layers and alkaline treated outer bark particles of white birch in the core layer
4	P_{no}	Mixed panel with non-oriented wood strands in the surface layers and untreated outer bark particles of white birch in the core layer
5	P_{no-f}	Mixed panel with non-oriented wood strands in the surface layers and a mixture of untreated outer bark particles of white birch (90% by weight) and wood fibres (10% by weight) in the core layer
6	P_{no-s}	Mixed panel with non-oriented wood strands in the surface layers and alkaline treated outer bark particles of white birch in the core layer
7	Reference	Control or reference panel with oriented wood strands (50% by weight in the core and 50% by weight in the surface layers)

The experimental design was set up with the help of a plan procedure of SAS software to fulfill a randomisation principle that eliminates subjectivity and ensure the independency of errors (Montgomery 1997). Three-layer pure wood strand reference

panels were also fabricated, and their properties were compared with those of mixed panels, using the least significance difference test (LSD) in a complete random design (CRD).

Particleboards manufacture and tests

The manufacturing parameters are listed in Table 2. The particles for each panel type were mixed in a rotating-drum mixer for 5 minutes. The panel was manually formed in a frame prior to its hot pressing, using a conventional steam-heated Diffenbacher press equipped with Press-Man, ARC's monitoring system. Test samples were prepared based on CSA (1993) specifications. The panels were conditioned at a temperature of 21°C and 65% relative humidity until they reached their equilibrium moisture content (four weeks). Then they were sanded to 11 mm final thickness before any test was carried out. Photos of manufactured panels are presented in Fig. 1.



Fig. 1. Samples of manufactured panels

Determination of Mechanical and Physical Properties

Tests samples were prepared based on ASTM D-1037-99 specifications (in ASTM Book, 2005), and the result of each test was compared with the value of the CSA (1993) standard. Vertical density profiles were determined from internal bond samples with a QMS X-ray density profiler, Model QDP-01X. The surface density was obtained from the maximum density point, and the core density was obtained from the minimum point of each respective zone of the vertical density profile. The modulus of elasticity (MOE^*) and the modulus of rupture (MOR^*) in the major axis were obtained from an average of three 314×75 mm samples for each panel. The modulus of elasticity (MOE^S) and the modulus of rupture (MOR^S) in the side axis were obtained from an average of

three 314×75 mm samples for each panel. Internal bond (*IB*) was obtained from an average of five 50×50 mm samples for each panel. Thickness swelling (*TS*) after soaking the samples in water for 24 hours was obtained from an average of two 150×150 mm samples for each sample. Linear expansion (*LE*) was obtained from an average of four (2 in the panel length and 2 in the panel width) 300×75 mm samples for each panel. *LE* was measured following a desorption from 65 to 50 % relative humidity (*RH*) and an adsorption from 50 to 90% *RH*. The *RH* conditions were obtained using a climatic chamber, model N0. WM – 906 – MP2H – 5 - SC/WC from Cincinnati Sub-Zero (CSZ).

Table 2. Manufacturing Parameters

Board size (width × length × thickness)	0.75 × 0.75 × 0.012 m (non-sanded) and 0.75 × 0.75 × 0.011 m (sanded)
Target board density	625 kgm ⁻³
Mass distribution	For 3-layers ; 25% (top), 50% (core), 25% (bottom) (based on oven-dry weight of all particles used) of all panels
Compaction ratio (Cr)*	5 for all mixed panel and 4 for the reference panel
Press plates temperature	200° C
Press pressure	180 KPa
Resin used	Phenol-formaldehyde (Borden Casco-resin, solid content: 52%). 8% (on oven-dry wood basis) were used to bond bark particles used in the core layers of all mixed panels and 5% were used to resinate wood strands in the mixed panels and in the reference panel.
Press closing time	30 seconds
Wax	1% (based on oven-dry wood basis) in the wood strands only.
Curing time	4 minutes
Press opening time	1 minute in three steps

*Cr = mat thickness/panel thickness

LE values were calculated as follows:

$$LE = [(L_2 - L_1) / L_1] \times 100 , \quad (1)$$

where LE is the linear expansion between 50 and 90 % RH (%); L_1 is the sample length at equilibrium of 50 % RH (mm); and L_2 is the final sample length after reconditioning to 80 % RH (mm).

RESULTS AND DISCUSSION

Density Profile

The density profiles of all six manufactured mixed panels were similar. Thus, only one profile among them was selected and drawn together with that of wood strands reference panel in Fig. 2 for comparison. The average density profile in the core mixed panel was higher than that of reference panel. This high value can be explained by the best compaction of small outer bark particles of white birch used in the core. The profile shape in the core of mixed panel was flatter and more regular than that of the wood strand reference panel because the bark particles used in the core were small and so compressed that there were no empty spaces among them. The maximum densities in the surface layers of mixed panel were less than those of wood strands reference panel. The reason could be the use of outer bark particles of white birch in the core, which leads to a compressibility reduction in the wood strands of surface layers.

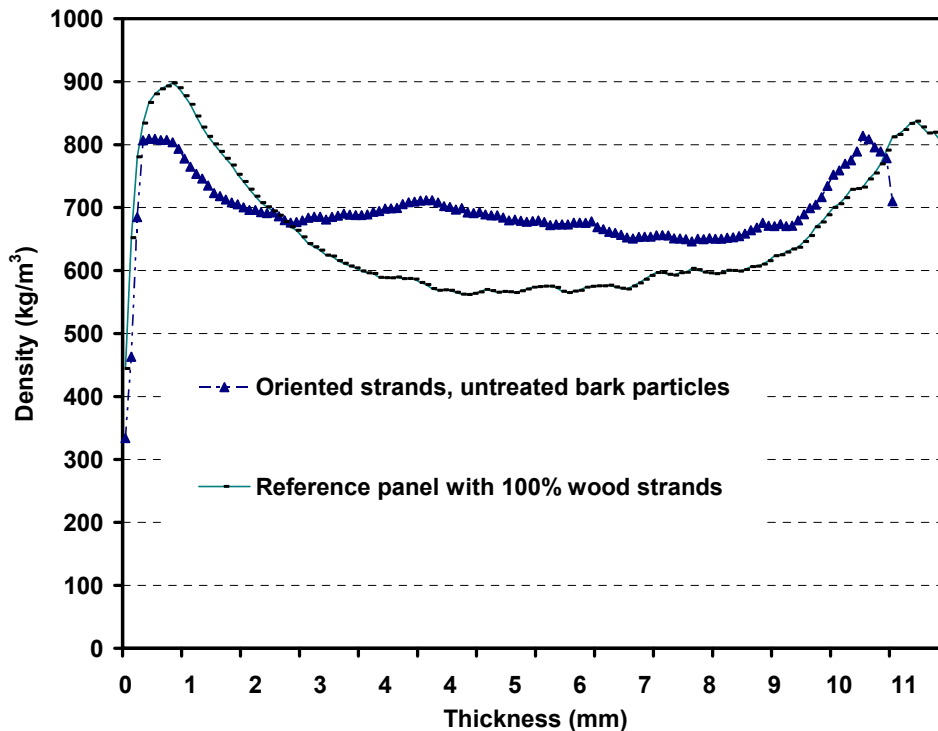


Fig. 2. Density profiles of wood strands reference panel and mixed panel with wood strands in the surface layers and untreated outer bark particles of white birch in the core

Results of Mechanical and Physical Property Tests

Modulus of elasticity (MOE^*) in the major axis

The MOE^* in the major axis is the MOE parallel to the orientation. These values are presented in Fig. 3. The MOE^* of all mixed panels with oriented strands in the surface layers were above the limit values required for the standard of O-1 and R-1 panel type. But the panels with non-oriented strands in their surface layers did not meet the requirements of O-1 panel type for the measured property, although the limit value of R-1 panel type was exceeded. The results of variance analysis ANOVA showed that the effect of strands orientation in the core layer were highly significant for MOE^* (Table 3). The highest values of MOE^* were obtained when wood strands were oriented in the surface layers (Fig. 3) The type of material used in the core layer of mixed panel did not influence MOE^* (Table 3). The MOE^* values of panels P_o and P_{o-s} were not statistically different from those of the reference. But the MOE^* values of the remaining four mixed panels were significantly lower than that of reference panel according to LSD test. The reason was mostly that the arrangement of wood strands was not oriented in their surface layers (Fig. 3).

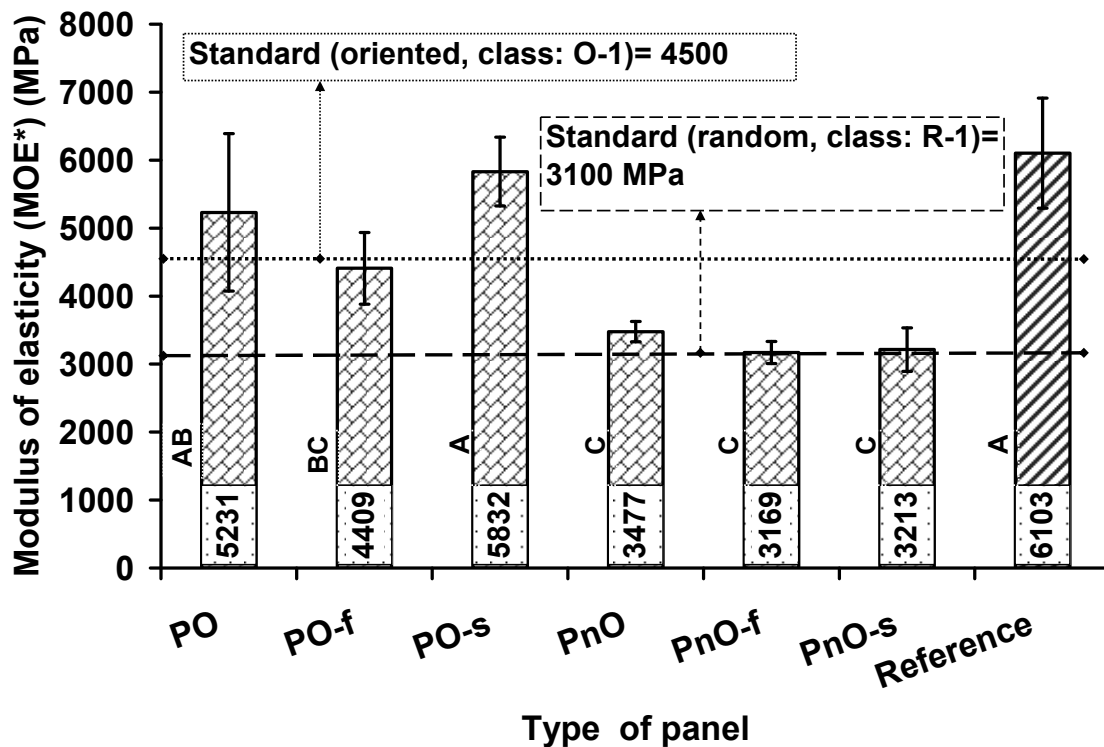


Fig. 3. Modulus of elasticity (MOE^*) in the major axis of manufactured panels: mean values and standard deviation.

(The letters on the left side of each histogram are from the results of LSD test. This test makes it possible to compare the measured property of each panel with that of reference panel. Thus, panels sharing the same letters with the reference were not statistically different from the latter)

Table 3. Summary of Variance Analysis (ANOVA) (df = degree of freedom, MOE^* = modulus of elasticity in the panel major axis, MOE^{ζ} = modulus of elasticity in the panel side axis, MOR^* = modulus of rupture in the panel major axis, MOR^{ζ} = modulus of rupture in the panel side axis, IB = internal bond, TS = thickness swelling, LE = linear expansion)

Source of variation	Physical and mechanical properties (F values)							
	df	MOE^*	MOE^{ζ}	MOR^*	MOR^{ζ}	IB	TS	LE
Block	2	0.09 ns	0.45 ns	0.20 ns	1.02 ns	0.45 ns	1.85 ns	0.42 ns
O	1	26.35 **	163.90 **	18.46 **	33.18 **	2.19 ns	0.06 ns	1.55 ns
M	2	1.47 ns	1.71 ns	1.49 ns	0.13 ns	16.45 **	60.48 **	0.60 ns
O*M	2	1.21 ns	7.07 *	0.76 ns	1.08 ns	0.57 ns	0.52 ns	0.06 ns
Contrasts								
O*((nt and ntf) Vs ts)	1	2.10 ns	4.80 ns	1.48 ns	0.22 ns	0.96 ns	0.81 ns	0.05 ns
O*(nt Vs ntf)	1	0.33 ns	9.33 *	0.04 ns	1.94 ns	0.19 ns	0.24 ns	0.07 ns

Description of abbreviations in the column of variation source : **O** = strands orientation in the surface layers (oriented strands versus non-oriented strands); **M** = type of material used in the panels's core layer: [**(nt)** = non-alkali treated bark particles, **(ntf)** = non-alkali treated bark particles mixed with wood fibres, **(ts)** = alkali treated bark particles]; **O*M** = interaction between (O) = orientation and (M) = type of material; **O*((nt and ntf)Vs ts)** = contrast between strands orientation and [non-alkali treated materials **versus** alkali treated bark particles]; **O*(nt Vs ntf)** = contrast between strands orientation and [non-alkali treated bark particles **versus** non-alkali treated bark particles mixed with wood fibres]; **ns** = non significant, * = significant at 0.05 probability level; ** = significant at 0.01 probability level

Modulus of elasticity (MOE^{ζ}) in the side axis

The MOE^{ζ} in the side axis is the MOE perpendicular to the orientation. These values are presented in Fig. 4. Mixed panels with random oriented strands in their surface layers met the requirement of O-1 and R-1 panels' types for the above mentioned property, whatever the type of material used in the core. The MOE^{ζ} values of panels with oriented strands in their surface layers were far below the standard of R-1 panel type, although the requirements of O-1 panel type were fulfilled. The results of ANOVA showed that the effect of strand orientation in the core layer was highly significant for MOE^{ζ} (Table 3). The best values of MOE^{ζ} were obtained when wood strands were not oriented in the surface layers (Fig. 4). The effect of material type in the core layer of a mixed panel was not significant, but the interaction between the orientation of wood strands in the surface layers and the type of material used in the core layer was significant (Table 3). The highest value of MOE^{ζ} was obtained with the mixed panel P_{no-s} (panel with: non-oriented wood strands in the surface layers and alkali treated bark particles in the core layer). The MOE^{ζ} values of panels P_{no} and P_{no-s} were not statistically different from those of the reference. But the MOE^{ζ} values of the remaining four mixed panels were significantly lower than that of reference panel according to LSD test. The reasons were firstly that the overlapping of oriented strands of the surface layers in the side axis was not stronger than that in the major axis and secondly that the strands in the core layer were replaced with small size particles of white birch outer bark (Fig. 4).

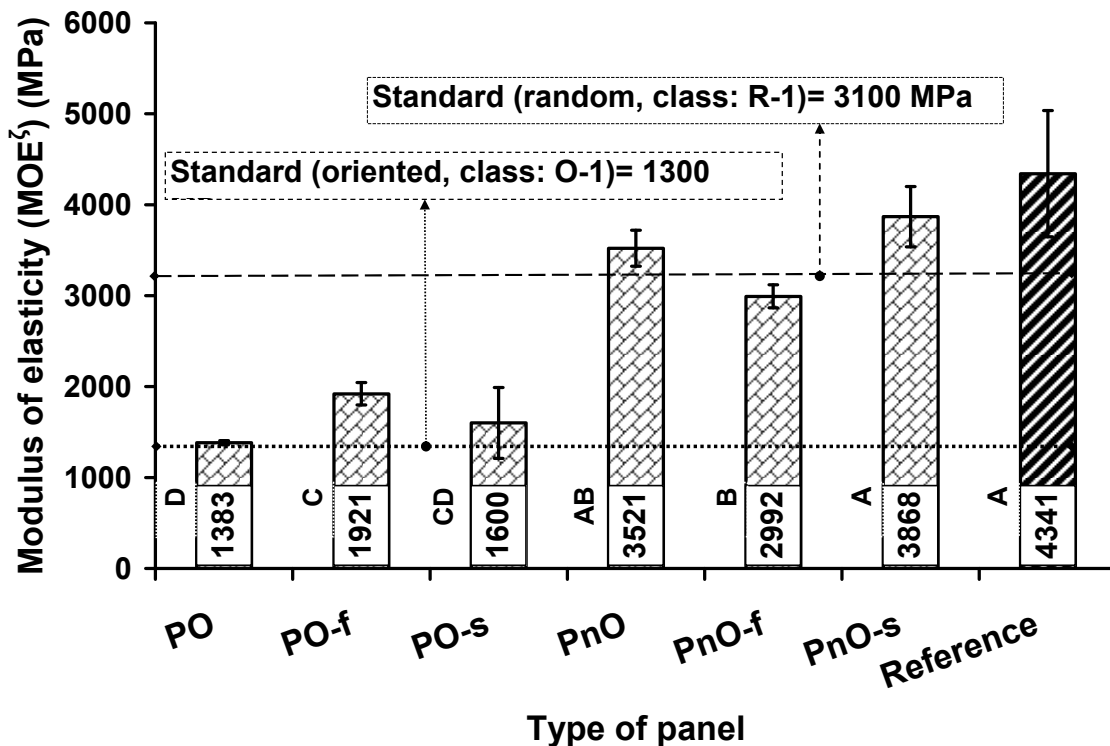


Fig. 4. Modulus of elasticity (MOE^{ζ}) in the side axis of manufactured panels: mean values and standard deviation. (The letters on the left side of each histogram are from the results of LSD test. This test allows comparison of the measured property of each panel with that of reference panel. Panels sharing the same letters with the reference were not statistically different from the latter)

Modulus of rupture (MOR^) in the major axis*

The MOR^* values in the major axis are presented in Fig. 5. The MOR^* of all mixed panels with oriented strands in the surface layers were above the limit values required by the standard of O-1 and R-1 panels' types. But the panels with non-oriented strands in their surface layers did not meet the requirements of O-1 panel type for the measured property, although the limit value of R-1 panels type was exceeded. The results of ANOVA showed that the effect of strands orientation in the core layer was highly significant for MOR^* (Table 3). The highest values of MOR^* were obtained when wood strands were oriented in the surface layers, and the mixed panel with oriented strands in the surface layers and alkali treated bark particles in the core had the highest value of the measured property. This value was even higher than that of reference panel (Fig. 5) The type of material used in the core layers of mixed panel did not influence MOR^* (Table 3). The MOR^* values of panels P_o and P_{o-f} were not statistically different from that of reference. The MOR^* value of panel P_{o-s} was significantly higher than that of the reference panel. But the MOR^* values of the remaining three mixed panels were significantly lower than those of reference panel according to the LSD test. The reason was mostly that the arrangement of wood strands was not oriented in their surface layers (Fig. 5).

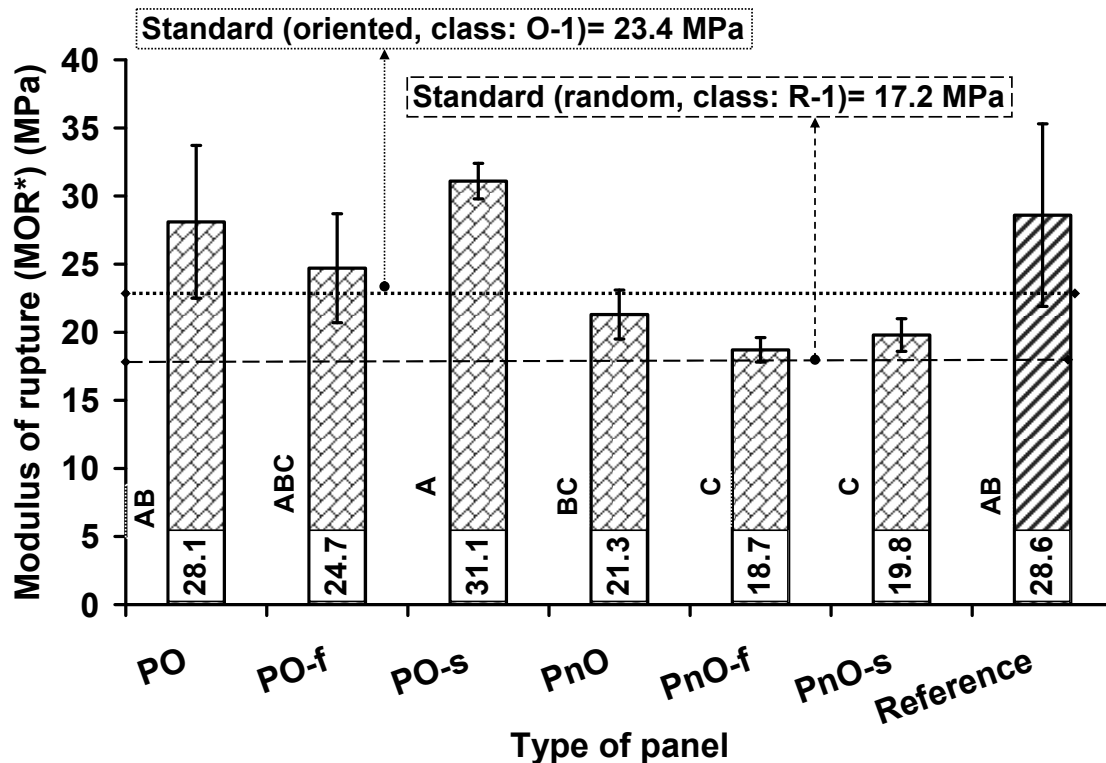


Fig. 5. Modulus of rupture (MOR^*) in the major axis of manufactured panels: mean values and standard deviation.

(The letters on the left side of each histogram are from the results of LSD test. This test makes it possible to compare the measured property of each panel with that of reference panel. Thus, panels sharing the same letters with the reference are not statistically different from the latter)

Modulus of rupture (MOR^{ζ}) in the side axis

The MOR^{ζ} in the side axis is the MOR perpendicular to the orientation. These values are presented in Fig. 6. Mixed panels with random oriented strands in their surface layers met the requirement of O-1 and R-1 panels' types for the above mentioned property, whatever the type of material used in the core. The results of ANOVA showed that the effect of strands orientation in the core layer was highly significant for MOR^{ζ} (Table 3). The best values of MOR^{ζ} were obtained when wood strands were not oriented in the surface layers (Fig. 6). The effect of material type in the core layer of mixed panel was not significant. The MOR^{ζ} values of panels P_{no} and P_{no-s} were not statistically different from those of the reference. But the MOR^{ζ} values of the remaining four mixed were significantly lower than those of the reference panel according to the LSD test (Fig. 6). The reasons are the same as those given in the last sentence of the measurement of (MOE^{ζ}) above.

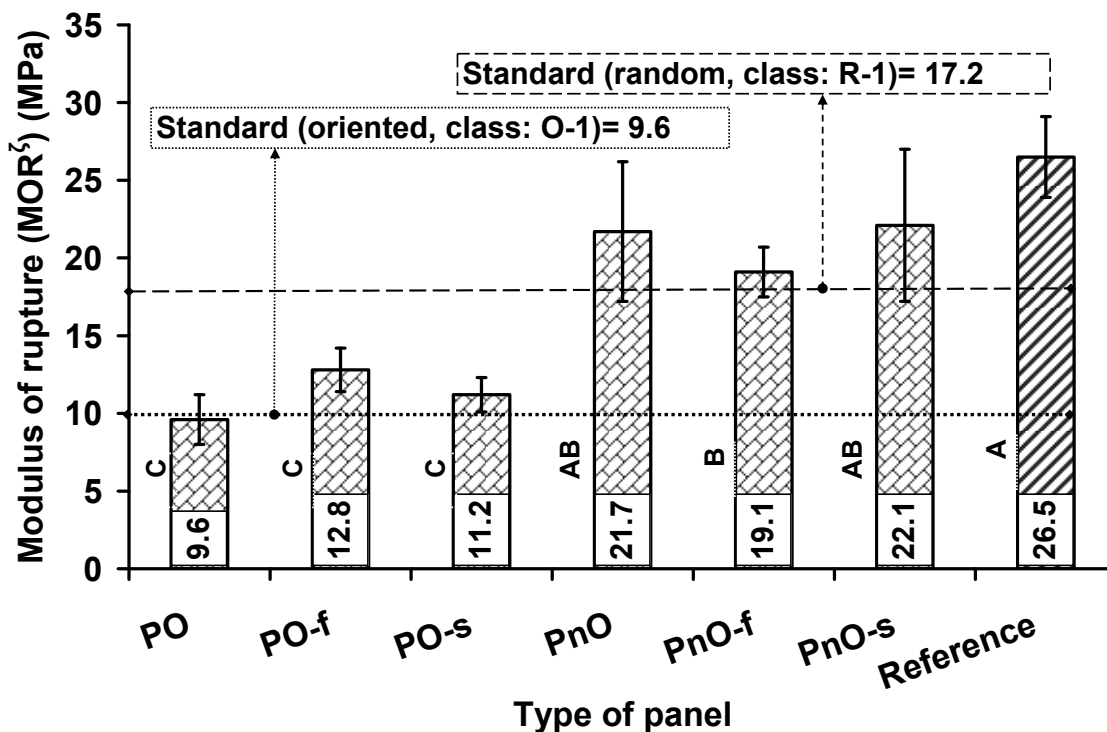


Fig. 6. Modulus of rupture (MOR^{ζ}) in the side axis of manufactured panels: mean values and standard deviation.

(The letters on the left side of each histogram are from the results of LSD test. This test makes it possible to compare the measured property of each panel with that of the reference panel. Thus, panels sharing the same letters with the reference are not statistically different from the latter)

Internal bond (IB)

These values are presented in Fig. 7. All mixed panels except the one with random oriented strands in the surface layers and a mixture of bark particles with wood

fibres in the core layer met the requirements of O-1 and R-1 panels' types for the above mentioned property, whatever the type of orientation of wood strands used in the surface layers. The results of ANOVA showed that the effect of strand orientation in the core layer was not significant for IB, but the effect of material type used in the core layer was highly significant (Table 3). The mixed panel with oriented strands in the surface layers and untreated bark particles in the core had the highest value for the measured property. This value was even higher than that of the control or reference panel (Fig. 7). The value of *IB* decreased drastically when a mixture of bark particle and wood fibres were used in the core layer. This is a proof that the bonding between these two different materials is weak. The *IB* values of all panels without wood fibres mixed with bark particles of white birch in the core layer were significantly higher than those of reference panels according to the LSD test (Fig. 7).

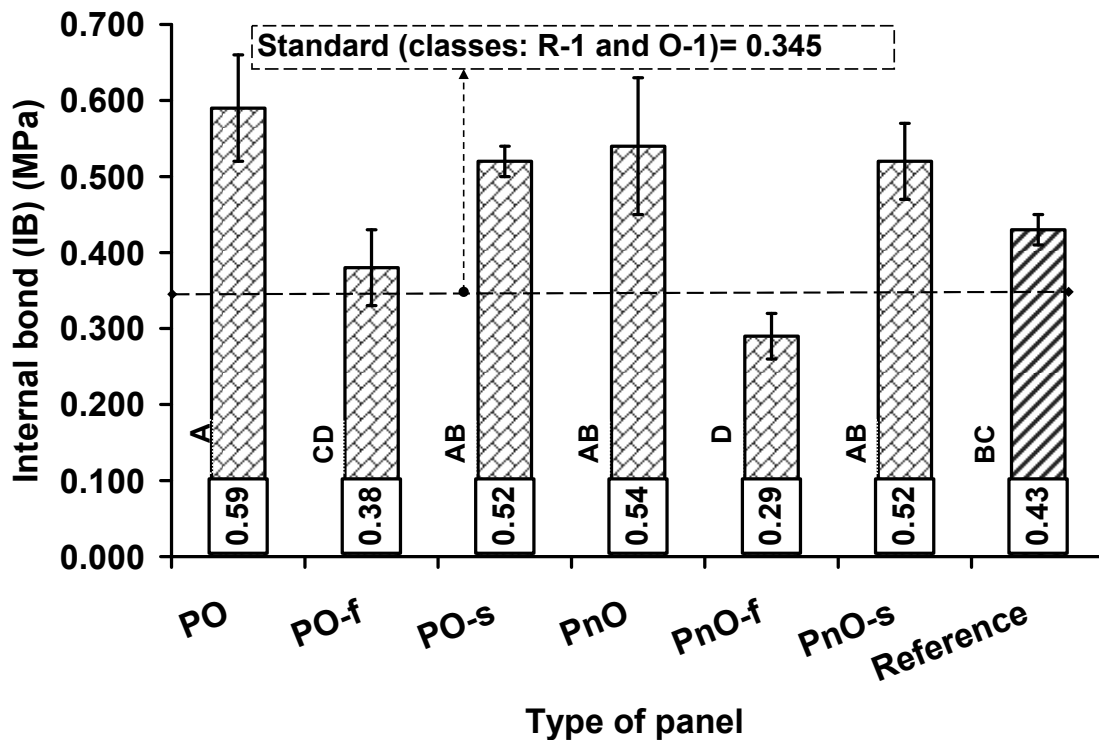


Fig. 7. Internal bond (*IB*) of manufactured panels: mean values and standard deviation. (The letters on the left side of each histogram are from the results of the LSD test. This test makes it possible to compare the measured property of each panel with that of reference panel. Thus, panels sharing the same letters with the reference were not statistically different from the latter)

Thickness swelling (TS) of manufactured panels

The values of *TS* are represented by the charts of Fig. 8. All mixed panels and the reference panel did not meet the specifications of O-1 and R-1 panel type for the above mentioned property. The results of ANOVA showed that the effect of strand orientation in the core layer was not significant for *TS*, but the effect of material type used in the core layer was highly significant (Table 3). The lowest values of this property were obtained

when untreated bark particles were used in the core, especially with the addition of wood fibres. The alkali treatment of bark particles made them rather more hydrophilic. This is the reason why the mixed panels with these treated bark particles in the core layer swelled more than 1.5 times than those with untreated bark particles.

The thickness swelling of all manufactured panels would have been improved to pass the standard requirement if they had been placed in an oven for 2 hours at 150°C immediately after hot pressing to enable the continuation of PF curing. This method was established by Chan *et al.* (2002) and is used routinely in OSB panel manufacture (hot stacking). This particular post-treatment was not done in the case of this work because the sizes of panels were too big to be placed easily in the small laboratory oven. The TS values of panels with alkali treated bark particles of white birch in the core layer were significantly higher than those of the reference according to the LSD test. The alkali treatment made the white birch bark particles more hydrophilic (Fig. 8).

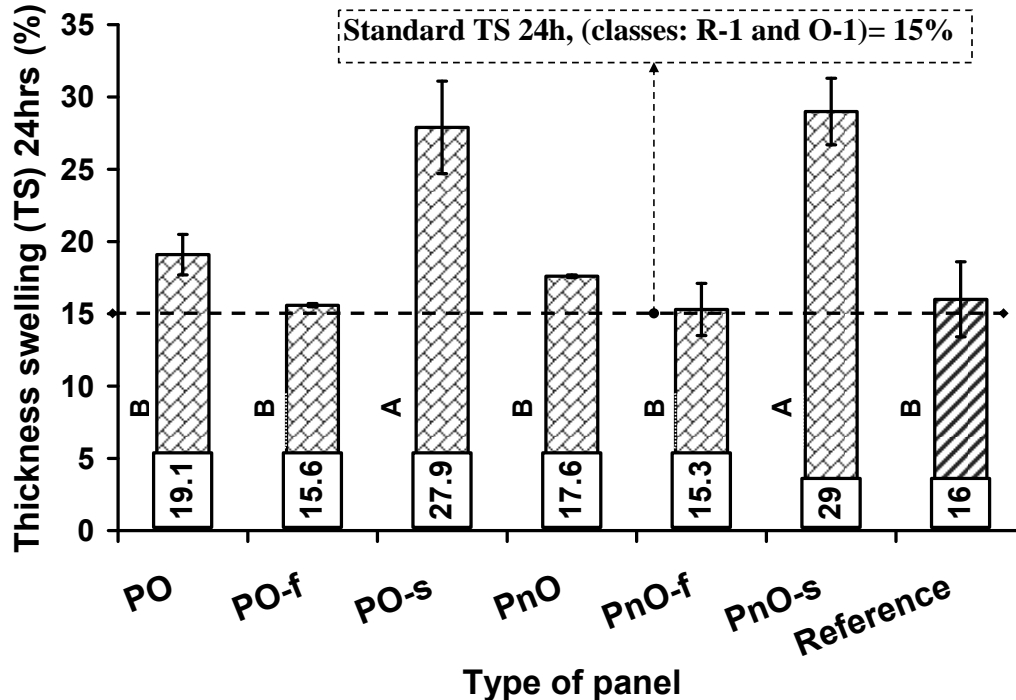


Fig. 8. Thickness swelling (TS) after 24 hours water immersion of manufactured panels: mean values and standard deviation.

(The letters on the left side of each histogram are from the results of LSD test. This test makes it possible to compare the measured property of each panel with that of the reference panel. Thus, panels sharing the same letters with the reference were not statistically different from the latter)

Linear expansion (LE) of manufactured panels

The values of *LE* are represented by the charts of Fig. 9. All mixed panels and the reference panel met the specifications of O-1 and R-1 panels' types for the measured property. Panels with a mixture of bark particles with wood fibres in the core had the lowest values of *LE*. The alkali treatment of bark particles did not influence the *LE*.

There was no significant difference between the *LE* of all mixed panels and that of the reference panel according to the LSD test.

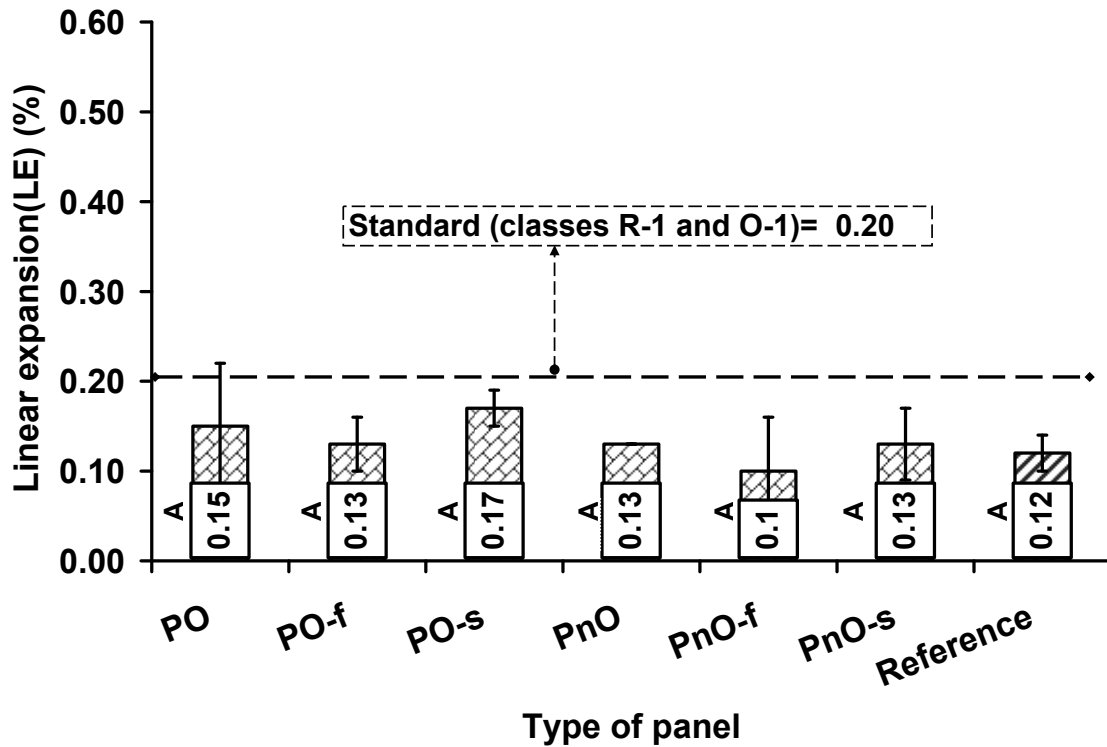


Fig. 9. Linear expansion (LE) of manufactured panels: mean values and standard deviation. (The letters on the left side of each histogram are from the results of LSD test. This test makes it possible to compare the measured property of each panel with that of the reference panel. Thus, panels sharing the same letters with the reference were not statistically different from the latter)

Regression between the measured property and the density of samples used

Table 4. Regression between the Measured Property and the Density of Sample Used (**MOE*** = modulus of elasticity in the panel major axis, **MOE ζ** = modulus of elasticity in the panel side axis, **MOR*** = modulus of rupture in the panel major axis, **MOR ζ** = modulus of rupture in the panel side axis, **IB** = internal bond, **TS** = thickness swelling, **LE** = linear expansion)

Regression	MOE* versus density	MOE ζ versus density	MOR* versus density	MOR ζ versus density	IB versus density	TS versus density	LE versus density
F-Value	0.36 ns	0.04 ns	0.61 ns	0.01 ns	60**	0.22 ns	0.97 ns
R ²	0.08	0.01	0.13	0.003	0.94	0.05	0.19

ns = non significant, ** = significant at 0.01 probability level

A regression was done between each measured property and the density of samples used in order to check if a variation observed in the measured property could be explained by the samples density (Collin, 2003). The results are presented in Table 4. A significant F- value for the regression was obtained only for the internal bond (IB). Therefore the determination coefficient $R^2 = 0.94$ means that 94% of the variation observed in the measurement of IB can be explained by the density of samples used. The main causes of this variation could be the difference among the materials used in the core layer on one hand and the hand formation of the mat, which was not well levelled, on the other hand.

CONCLUSIONS

1. The addition of wood fibres to bark particles used in the core layer did not improve the mechanical properties of manufactured mixed panels.
2. The *MOE* and *MOR* in the mixed panels' major axis were higher when the wood strands in the surface layers were oriented.
3. The *MOE* and *MOR* in the mixed panels' side axis were higher when the wood strands in the surface layers were not oriented.
4. The *TS* values of all mixed panels didn't pass the standard requirements because the post treatment (in an oven for 2 hours at 150°C) of these panels was not done immediately after the hot pressing.
5. The *TS* was negatively affected by the alkali treatment of white birch outer bark particles.
6. All manufactured panels passed the requirements of *LE* and there were no significant differences among the measured *LE* values.
7. The statistical analysis method used made it possible to choose the panel with non-oriented wood strands in the surface layers and alkali treated bark particles in the core layer as the best by taking into account only the bending strengths in both major and side axes of the panel.
8. The method used made it possible to replace 50% of wood strands with white birch outer bark (by oven-dry weight of total particles in the panel) in each manufactured panel.
9. The produced mixed panels can be used as siding panels and for the fabrication of boxes, bins, and commercial shelving (Brulotte *et al.* 2004).
10. As recommendation, this type of panel can also be manufactured with a thickness of 20 mm or more to be used as floor panels.

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