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ORIGINAL PAPER

Improving physical and mechanical properties in particleboard by recycled polyethylene and canola residues

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Abstract Improving effects of recycled polyethylene on dimensional stability, mechanical properties, and reduction in adhesive consumption of particleboard made from canola residues were studied here. Canola residues were consumed at 0, 30, and 50 % consumption levels, based on the dry weight of wood particles. Recycled low-density polyethylene was also consumed at two levels of 20 and 30 %. Urea–formaldehyde resin was used for all treatments at three levels (6, 8, and 10 %). Results showed that polyethylene had significant improving effects on all the physical and mechanical properties. Increase in canola content, however, increased modulus of rupture and modulus of elasticity due to the more slenderness ratio of canola residue, but it decreased the internal bond and physical properties because of the higher specific surface area of canola particles. Properties of the panels made from 30 % canola residues, 30 % polyethylene, and 8 % urea–formaldehyde resin were in compliance with the EN 312-2 standards. It can be concluded that the improving effects of recycled polyethylene can compensate for part of the urea–formaldehyde resin, and therefore, lower urea–formaldehyde content can be used, lowering the production costs due to high-value urea–formaldehyde resin. At the same time, the potentiality of formaldehyde emission into the atmosphere would also be decreased.

Keywords Agricultural residue · Composite board · Particleboard · Polyethylene · Recycling · Urea formaldehyde binder (UF) · Wood plastic composite (WPC)

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Introduction

Disposed plastics are an important environmental concern in the modern world; they are not bio-degradable. So, if by any means, there would be a possible way to use them in industry of any kinds, and two goals will be achieved at the same time: First, the problem of disposing a non-biodegradable material would be solved, and second, a value would be added to a waste material. In this connection, composite boards offer a nearly homogeneous structure (Eshaghi et al. 2013); furthermore, raw materials may be used without restrictions as to the shape and size (Taghiyari et al. 2013, 2014), and there are many studies to find methods for limitation of formaldehyde emission and improve the properties (Stockel et al. 2012; Valenzuela et al. 2012). Composite boards and profiles are therefore expanding worldwide. It was reported that recycled plastic bags were replaced by part of the isocyanate resin in particleboards made from creeping wild rye (*Leymus triticoides*); the properties of the panels were found to be improved (Baoguo et al. 2009).

In the meantime, there are huge amount of canola harvested in Iran; however, no industrial applications have ever been introduced to use it as a raw material. Similar studies on using bagasse, canola, and hemp residues mixed with wood chips in various proportions were reported to have promising results (Nikvash et al. 2010).

In the present study, therefore, the use of recycled polyethylene as well as canola stem residues in different proportions was studied to find out whether part of the urea–formaldehyde resin (UF resin) could be replaced by recycled polyethylene and whether canola stem residue could also be mixed with wood particles in the particleboard production process.

Materials and methods

Materials

Wood particles were procured from Shomal Particleboard Manufacturing Factory, located in Gonbad city in Iran; they comprised of a mixture of five different hardwood species, including poplar, beech, alder, maple, and hornbeam. Canola residues (*Brassica napus* L.) were procured from Kolaleh district, located in Golestan Province in the Northern of Iran. Specifications of the industrial wood particles and canola stem residues are summarized in Table 1. The residues were mixed with wood particles on 0, 30, and 50 % proportions, based on the dry weight of the wood particles. Recycled low-density polyethylene (LDPE) chips were procured from Ferdowsi Plastic Recycling Factory in Mash-had city, and they were mixed with wood particles and canola residues on 20 and 30 % proportions. Furthermore, urea–formaldehyde resin (UF resin) was bought from Samed Adhesive Manufacturing Factory in Mashhad city; specifications of the UF resin are summarized in Table 2. UF resin was used at three consumption levels of 6, 8, and 10 %, based on the dry weight of the solid materials (wood particles, canola residues, and polyethylene chips). Totally, there were 18 treatments; for each treatment, three panel replications were produced.

Panel production

The ingredients of each composite formulation were first weighed to a 0.01 g precision; they were manually mixed in a rotary drum. Once the solid proportions were rotated for 10 min, making sure they were evenly mixed together, UF resin was sprayed on them while the rotary drum was still rotating. A 420 × 270 mm mat was then formed in a cold former. The mat was put in a hot-press for 6 min; temperature of the upper and lower hot-plates was set at 180 °C. The thickness of the mat was monitored by 16 mm stop-bars at the left and right sides of the mat. Totally, 54 panels were produced for the 18 treatments in the present study.

Mechanical properties

Three-point static flexural test was performed according to the EN 310 (1993) specifications. Nominal size of the specimens was 370 × 50 mm, with loading speed of 4 mm/min. Modulus of rupture (MOR) and modulus of elasticity (MOE) were calculated (Eqs. 1, 2). The static bending test was performed using center-point loading over a 350-mm span. The loading speed was 2 mm/min. All tests were conducted using an Instron 4486 testing machine, model 4486 (USA). Internal bond was measured in accordance with the EN 319 (1993) specifications (Eq. 3); specimen size for the internal bond tests was 50 × 50 mm

$$\mathrm{MOR} = \frac{1.5\,\mathrm{FL}}{\mathrm{bd}^2}\ (\mathrm{MPa}) \tag{1}$$

$$\mathrm{MOE} = \frac{\mathrm{FL}^3}{4\mathrm{bd}^3\mathrm{D}}\ (\mathrm{MPa}) \tag{2}$$

$$\mathrm{IB} = \frac{\mathrm{F}_{\mathrm{max}}}{\mathrm{A}}\ (\mathrm{MPa}). \tag{3}$$

Physical properties

Water absorption and thickness swelling were measured after 2 and 24 h immersion in distilled water in accordance with the standard EN 317 (1993) specifications. The specimen dimensions were 50 × 50 mm. Weight of the specimens was measured by a digital scale with 0.01 g precision. Thicknesses of the center point as well as the four corners (totally, five points) were measured by a digital caliper with a 0.01-mm precision.

Statistical analysis

Statistical analysis was conducted using SAS software program, version 9.2 (2008). Factorial analysis was performed to discern significant difference at 95 % confidence level. Hierarchical cluster analysis, including dendrogram

Table 1 Specifications of the wood and canola particles

Particle type	Length (mm)	Width (mm)	Thickness (mm)	Slenderness ratio	Flatness ratio	Aspect ratio	Density (g/cm^3)
Industrial wood particle	11.44	2.36	0.58	19.35	3.96	4.74	0.6
Canola stem residues	18.82	2.47	0.41	43.95	5.73	7.49	0.25

Table 2 Specifications of the urea formaldehyde (UF) resin

Properties	Density (g/cm^3)	Solids (%)	pH	Viscosity (cP)	Gel time at 100 °C (s)
Values	1.23	59	6.8–7.1	200–240	44–46

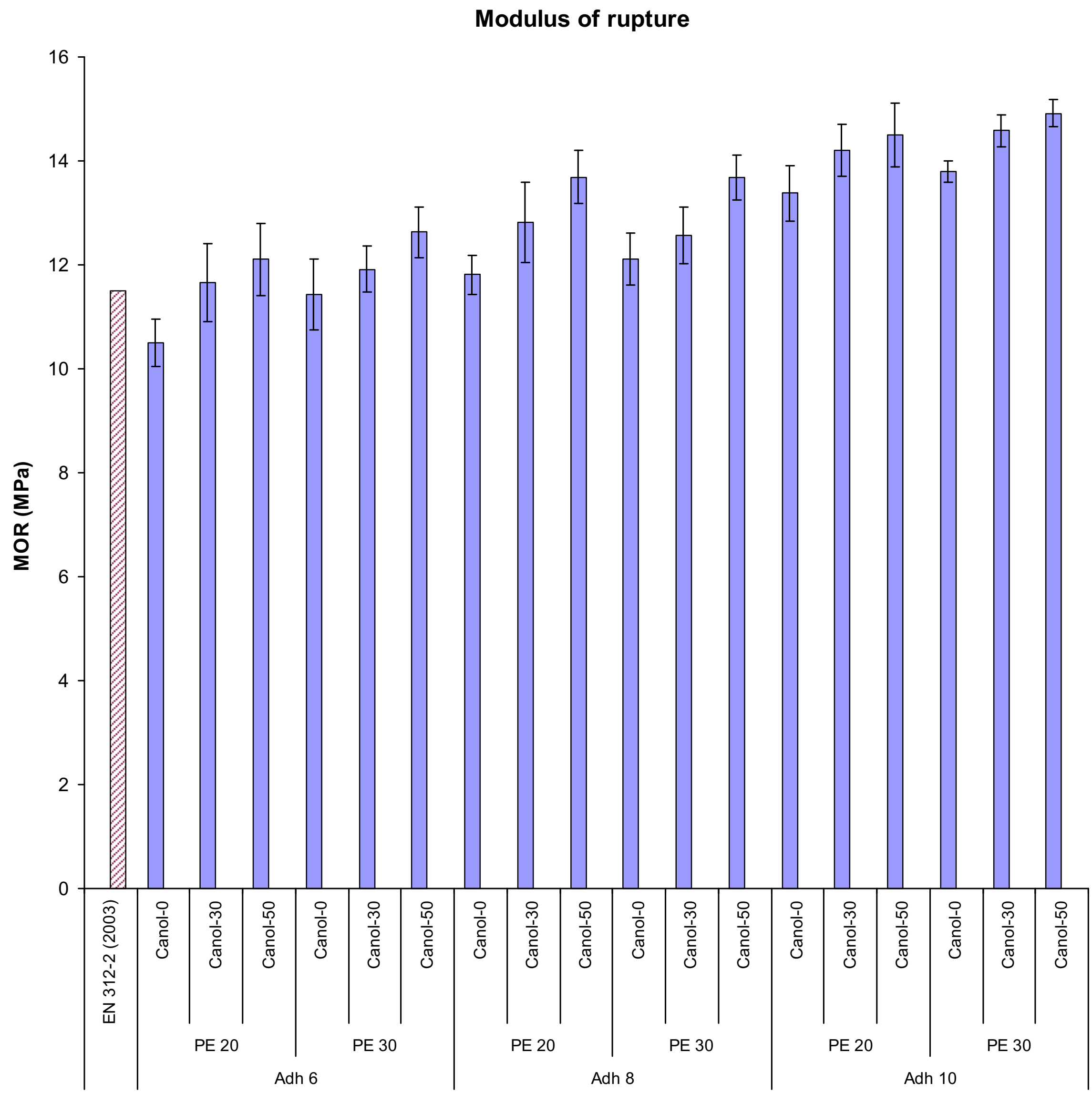

Fig. 1 Modulus of rupture (MOR) in the 18 treatments (MPa) (*EN* EN standard, *PE* polyethylene, *Canol* canola content, *Adh* adhesive content) (*values* represent the averages of each variable. *Error bars* represent one standard deviation)

and using Ward methods with squared Euclidean distance intervals, was carried out by SPSS/19 (2010).

Results and discussion

Results indicated that the highest MOR (14.9 MPa) was found in the treatment with the highest adhesive content (Adh10), the highest polyethylene content (PE30), and the highest canola content (Canol50) (Fig. 1). The lowest MOR was also found in the treatment with the lowest Adh, PE, and Canol contents (10.5 MPa). A clear increase in MOR values was observed with the increase in the canola content. Excluding treatments with the lowest adhesive content (6 %), the MOR values of all the other treatments were acceptable in comparison with the EN standard values.

The highest MOE value (2282 MPa) was found in the same treatment with the highest MOR (Fig. 2). An increase in MOE was observed as the adhesive as well as canola content increased.

All treatments, without an exception, showed higher internal bond values than the EN standard value (Fig. 3). The highest internal bond (IB) value was observed in the treatment with the highest PE and adhesive value, but the lowest canola content (Adh10-PE30-Canol0). The highest IB was 240 % more than the EN standard value. Clear increasing trend was found in IB values as the adhesive and

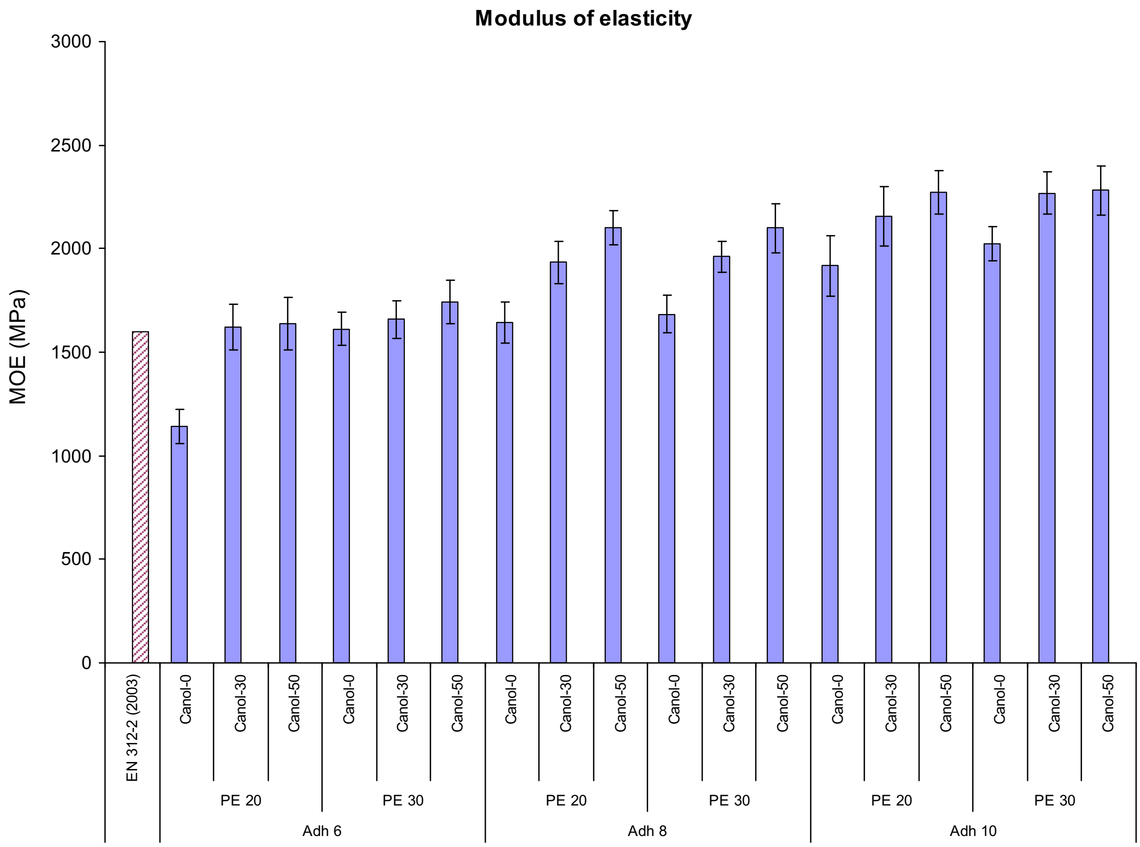

Fig. 2 Modulus of elasticity (MOE) in the 18 treatments (MPa) (*PE* polyethylene, *Canol* canola content, *Adh* adhesive content) (*values* represent the averages of each variable. *Error bars* represent one standard deviation)

polyethylene contents increased; however, addition of canola showed a significant decreasing effect on all treatments.

The lowest water absorption (WA) and thickness swelling (TS) were found in the treatment with 10 % adhesive content, 30 % of polyethylene, and without any canola content (Figs. 4, 5). Increase in the canola content had a significant increasing effect on both of the physical properties (WA and TS). Increase in adhesive content showed an improving effect on water absorption; however, it didn't show any effect on treatments without canola content.

Increase in the polyethylene content significantly increased the MOR values in all treatments (Fig. 1). Apart from Adh6-PE20-Canol0 treatment which was below the EN standard, all other treatments showed higher MOR values than the standard specifications. This clearly indicated that the recycled polyethylene could compensate for the decrease in adhesive content; that is, the low-value recycled polyethylene could be used for part of the expensive UF resin in the composite matrix. Polyethylene had the same improving effects on the MOE values. As to the internal bond, all treatments showed significant higher IB values in comparison with the EN specifications. The IB values increased more than 200 % in some treatments. This clearly showed the significant effect of polyethylene in binding wood particles in the core section of the mat, significantly increasing the internal bond. In fact, the core section of composite panels has the least compression ratio in comparison with the surface layers; the significant high increase in the IB values showed that polyethylene could solve this problem and overcome the low compression ratio, and consequently low IB, in the central layer of the wood particle composite panel. It may then be concluded that part of the resin consumption can be substituted with recycled polyethylene to both reduce the production costs through the application of low-value polyethylene residues and add value to a waste material that has brought some environmental concern due to the fact that it is not biodegradable; at the same time, it increases the mechanical properties.

Increase in the polyethylene content significantly increased the physical properties of water absorption and thickness swelling (Figs. 4, 5). It may then be concluded that not only the mechanical properties would increase by adding waste polyethylene in the composite matrix, but it would also improve the physical properties as well.

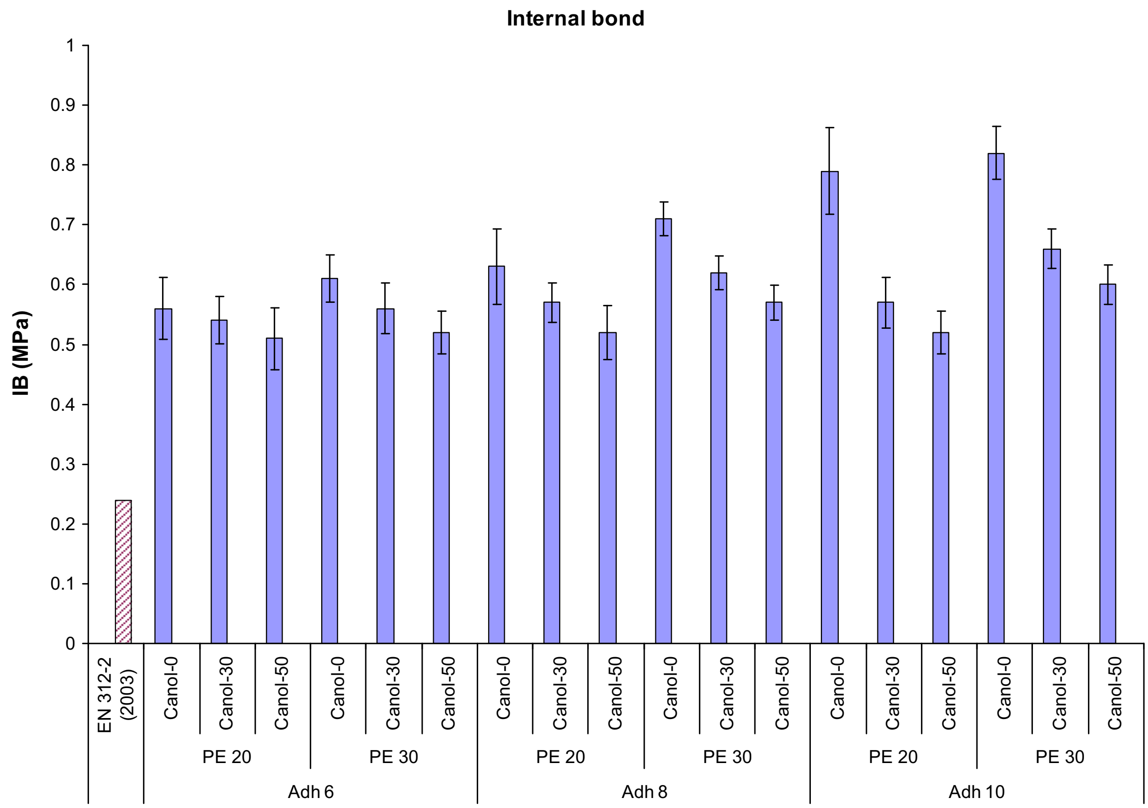

Fig. 3 Internal bond (IB) in the 18 treatments (MPa) (*EN* EN standard, *PE* polyethylene, *Canol* canola content, *Adh* adhesive content) (*values* represent the averages of each variable. *Error bars* represent one standard deviation)

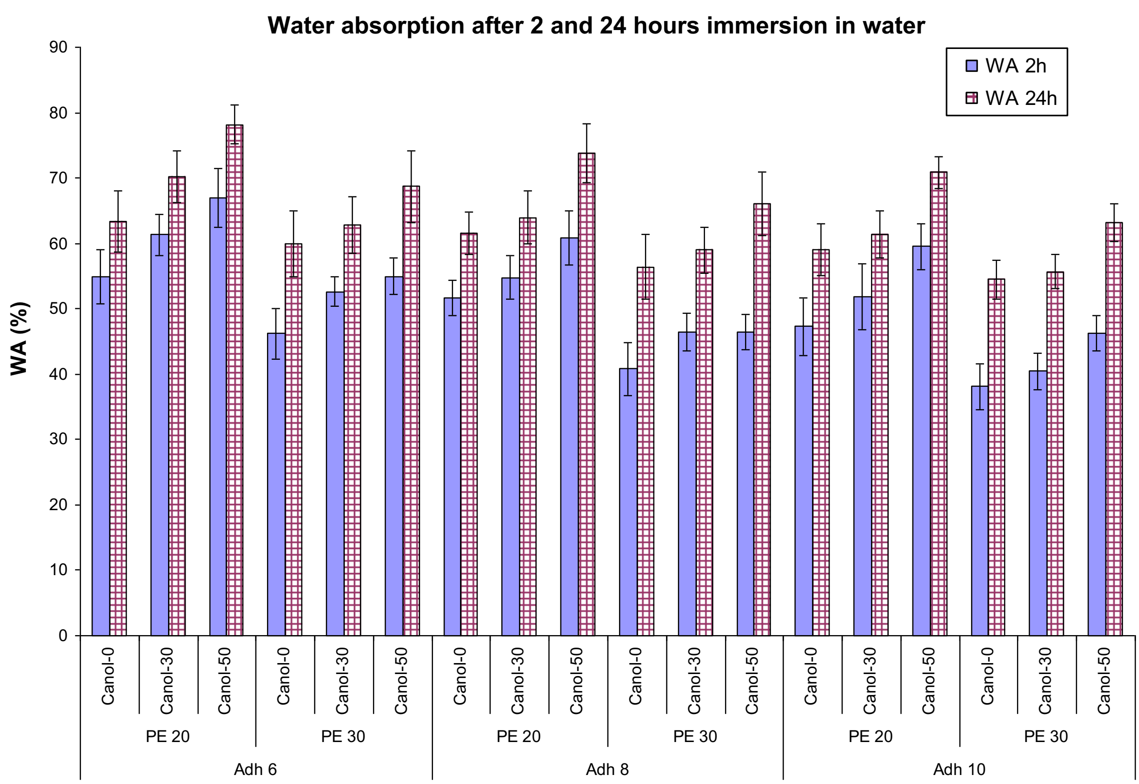

Fig. 4 Water absorption (WA) after 2 and 24 h immersion in distilled water in the 18 treatments (%) (*PE* polyethylene, *Canol* canola content, *Adh* adhesive content) (*values* represent the averages of each variable. *Error bars* represent one standard deviation)

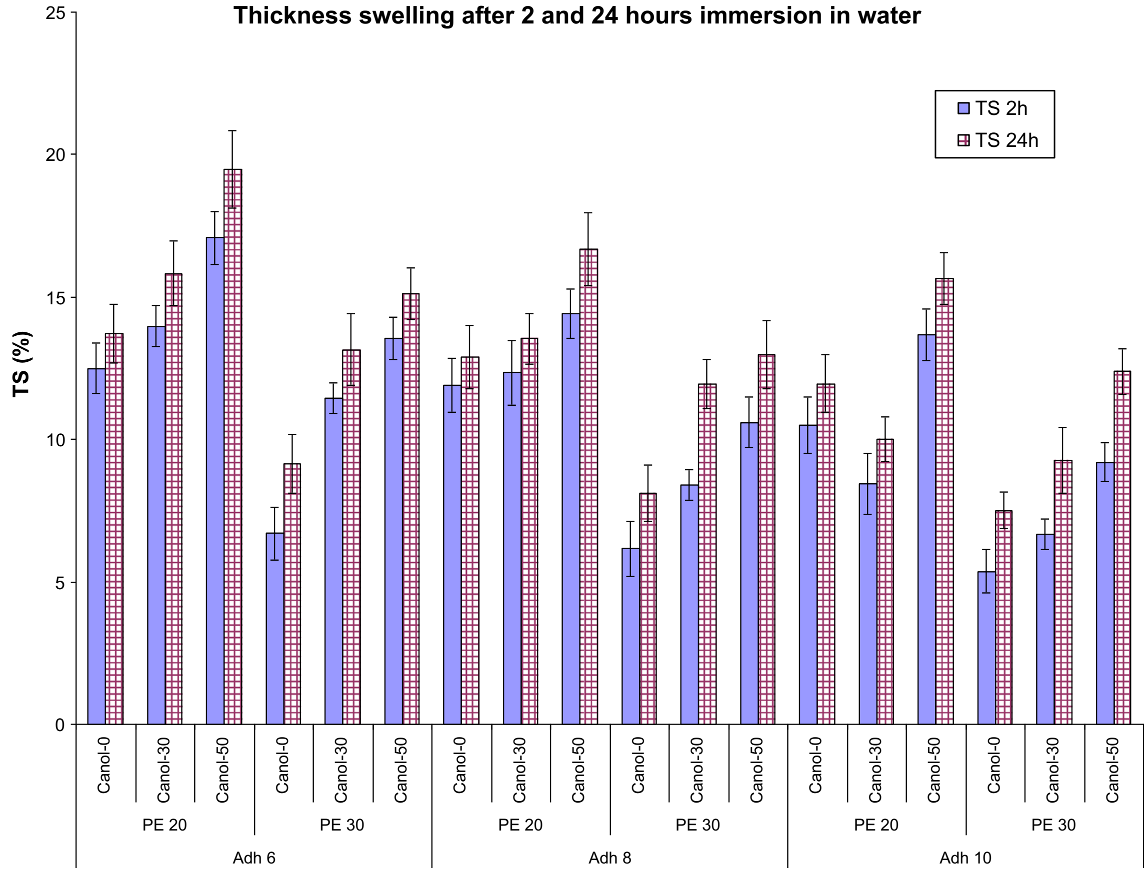

Fig. 5 Thickness swelling (TS) after 2 and 24 h immersion in distilled water in the 18 treatments (%) (*PE* polyethylene, *Canol* canola content, *Adh* adhesive content) (*values* represent the averages of each variable. *Error bars* represent one standard deviation)

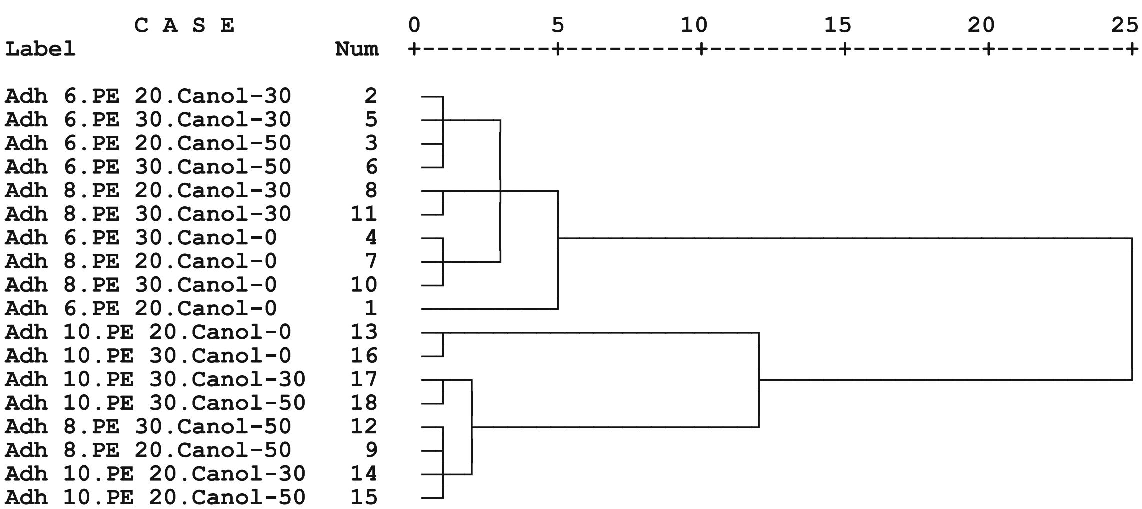

Fig. 6 Cluster analysis among the 18 treatments based on the mechanical properties, including modulus of rupture, modulus of elasticity, and internal bond (*PE* polyethylene, *Canol* canola content, *Adh* adhesive content)

Limiting UF resin consumption would have another privilege as far as the health issues are concerned: It will decrease formaldehyde emission in the living environment. Although utilization of UF resin is not restricted in some parts of the world (Taghiyari and Farajpour Bibalan 2013; Taghiyari et al. 2014), its limitation to as much extent as possible would be beneficial to people. Using polyethylene in the particleboard matrix would not only improve

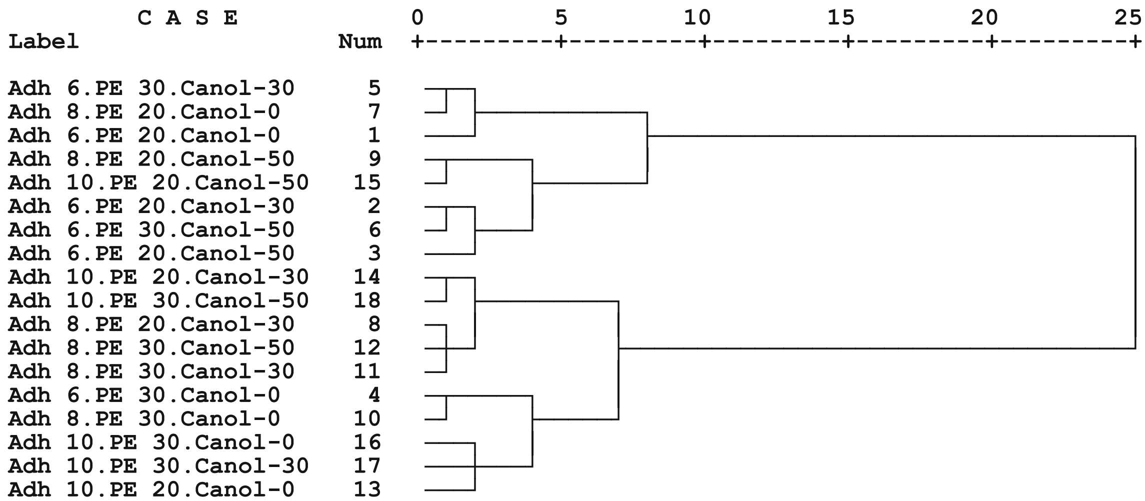

Fig. 7 Cluster analysis among the 18 different treatments based on the physical and mechanical properties (modulus of rupture, modulus of elasticity, internal bond, water absorption and thickness swelling after 2 and 24 h immersion in water) (*PE* polyethylene, *Canol* canola content, *Adh* adhesive content)

physical and mechanical properties, but also decrease the amount of formaldehyde emissions when the panels are to be used as home and office furniture.

Increase in the canola content resulted in significant increase in MOR and MOE values. This increase was related to higher aspect ratio of the canola residue particles. Similar increase in the MOR and MOE properties as to the increase in slenderness ratio was previously reported by Moslemi (1974). Lower compression ratio, and the consequent formation of micro-cavities in the composite matrix, was also reported to significantly increase liquid and gas permeability (Taghiyari 2013). Increase in the canola content, however, had negative impact on the internal bond, water absorption, and thickness swelling. In fact, the higher specific surface area of canola residues, due to its significant lower density (Table 1), limited the amount of resin applied to the surface of the particles, resulting in the significant negative effects on these properties (Doosthoseini 2007).

Cluster analysis among the 18 different treatments based on the three mechanical properties of MOR, MOE, and IB showed clear distinction between the six treatments with the lowest adhesive content of 6 % and the six treatments with the highest adhesive content of 10 % (Fig. 6). The four Adh6 % treatments with canola contents of 30 and 50 % were significantly clustered together; however, the two Adh6 % treatments with no canola content were clustered with those treatments having 8 % of adhesive. Although increase in canola content had increasing effects on MOR and MOE, it had decreasing effect on IB (Figs. 1, 2, 3); the way the two Adh6 % treatments with no canola content were clustered showed that the effect on IB values on the overall clustering was significantly higher than MOR and MOE. Similar effects of canola content were observed on the clustering of treatments with 10 % of adhesive; the two Adh10 % treatments with no canola content were clustered significantly different with the other four Adh10 % treatments. The six treatments with 8 % adhesive content were spread among the other treatments with 6 or 10 % adhesive content, showing the interaction between adhesive and canola contents. It is to be noted that all Adh8 % treatments with the same canola content (0, 30, or 50 %) were closely clustered together. Based on the overall clustering of the treatment, it may be concluded that the effects of adhesive and canola contents were more significant than the effect of polyethylene contents of 20 and 30 % on the mechanical properties.

In a rather similar way, the cluster analysis based on all the physical and mechanical properties showed general effects of adhesive content on the overall clustering of the 18 treatments: that is, treatments with adhesive contents of 6 and 10 % were clustered significantly different (Fig. 7); however, there were two exceptions: Adh10-PE20-Canol50 and Adh6-PE30-Canol0. The two variables of PE and canola contents did not show any clear trends in clustering based on both physical and mechanical properties. It may therefore be concluded that the effects of the variables on physical or mechanical properties, as well as their interactions on each other, resulted in the clustering without as much clarity as it was obtained when only mechanical properties were studied. This was due to the fact that adhesive content had improving effect on both physical and mechanical properties; however, canola content showed improving effects on MOR and MOE, but IB, WA, and TS were deteriorated.

Based on the findings of the present research project, it may be concluded that canola can be considered to provide part of the raw materials to manufacture wood composite panels. Previously, sycamore leaves and CCA-treated pine wood were used as part of the lignocelluloses materials for the production of wood plastic composites with promising results (Kamdem et al. 2004; Aghakhani et al. 2013).

Conclusion

Effects of the addition of two waste materials, recycled polyethylene and canola stem residues, to industrial wood particles on the physical and mechanical properties were studied here. Based on the obtained results, it can be concluded that the recycled polyethylene can be used to provide the possibility to apply the lower resin content of 8 % in particleboard. Using recycled polyethylene, the physical and mechanical properties would be even improved. Moreover, reduction in urea–formaldehyde resin can also provide the further advantage of lower formaldehyde release. As to the canola stem residue, due to its lower density as well as higher specific surface area, some of the properties increase (MOR and MOE) and some others decrease (IB, WA, and TS). The increase is due to the lower density of canola and the subsequent increasing effect it has on the compression ratio of the composite panels; the decreasing effect is due to the more surface area and the consequent more need for adhesive content. The ultimate canola content would therefore be dependant on the final application of the panel produced; if the mechanical properties are of vital importance, higher canola content levels can be used, whereas if the physical properties are vital to the end users, lower consumption levels would be recommended.

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