Effect of Pretreatment of Raw Material on Properties of Particleboard Panels Made from Wheat Straw

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The objective of this study was to evaluate properties of experimental particleboard panels manufactured from wheat straw that had been pretreated with acetic anhydride, soapy solution, hot water, or steam. Wheat straw particles were mixed with commercially manufactured wood particles at a ratio of 60%. Control straw particleboards with non-treated straw and wood particles were also produced. The results showed that the pretreatment of wheat straw significantly improved both the physical and mechanical properties of the straw particleboards. Panels made from wheat straw treated with a 9% solution of acetic anhydride or boiled in a soapy solution resulted in the highest mechanical properties, with an increase in bending strength values. Regarding internal bond strength, the samples made from wheat straw particles treated with acetic anhydride and a soapy solution had 2 and 3 times higher values, respectively, than those of non-treated samples. It seems that the pretreatment of wheat straw had a greater effect on the thickness swelling of the specimens than on their water absorption.

Keywords: Wheat straw; Pretreatment; Particleboard; Urea formaldehyde resin; Acetic anhydride; Hot water

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INTRODUCTION

A strong trend exists for using underutilized non-wood species and agricultural waste as raw material to manufacture composite panels. These approaches could result in reductions in deforestation rates in many countries and also conversion of such resources into value-added panel products (Bekhta and Hiziroglu 2010). Wheat straw is one of the most widely available lignocellulosic materials in the world (Markessini *et al.* 1997). Currently, wheat straw is not used as efficiently as it should be, and land filling or open burning are common practices for this resource that create significant environmental problems (Sauter 1996).

The structure of wheat straw fiber is morphologically different and more complex than that of wood (Robson and Hauge 1993). Straw fibers are relatively shorter and smaller, with reduced mechanical properties compared with wood fibers (Rexen 1975; Grigoriou 2000). The bulk density of straw particles is one-third lower than typical wood particles (Grigoriou 2000). In general, the chemical composition of wheat straw is similar to that of wood, containing cellulose, hemicellulose, lignin, and a certain percentage of extractives. The major difference in chemical composition between the two materials is the high content of silica and wax in wheat straw, which are mainly located on the surface layer (Rowell 1992). Wheat straw also has lower cellulose and higher lignin and hemicellulose contents than typical softwood species (Markessini *et al.* 1997).

Limited commercial attempts have been made to manufacture wheat straw panels in Canada (Cooper *et al*. 1999). Urea formaldehyde (UF) adhesive is the most commonly used binder in wood composite manufacturing in many countries. More than 90% of particleboards are bonded with UF resin, which creates strong bonds (Dalen and Shorma 1996; Luo and Yang 2010). Urea formaldehyde is also cost-efficient and results in excellent physical and mechanical properties of the panels, although it has some disadvantages, such as formaldehyde emissions, which cause significant environmental and health concerns (Grigoriou 2000; Bekhta and Salabay 2009). However, in the case of wheat straw, UF exhibits several problems in achieving the desired standards for the physical and mechanical properties of panels due to the high silica and wax content, as well as the high pH and acid buffering capacity of wheat straw (Sauter 1996; Hague *et al.* 1998). The most important of the parameters listed above is the layer of wax on the wheat straw surface, which inhibits adhesion with the UF binder. Poor bonding of particles adversely affects all of the basic properties of the final product.

Polymeric isocyanate (pMDI) and MDI adhesives are considered the most effective for producing straw-based composites with enhanced characteristics (Heller 1980). Panels manufactured using MDI-type binders have satisfactory physical and mechanical properties and meet standard requirements (Wasylciw 1998). They are also lightweight, biodegradable, and do not produce formaldehyde emissions (Borda *et al*. 1999). However, the price of MDI is about 10 times that of UF, which substantially increases the overall production cost.

In previous studies, in addition to UF- and MDI-based adhesives, polyester, gypsum, and thermoplastic polymers were used to produce experimental wheat straw panels (White and Ansell 1983; Thole and Weiss 1992; Panthapulakkal *et al.* 2006). Furthermore, the low bonding ability of UF with wheat straw particles was improved by employing cross-linking agents and other additives (Bryant 1968; Rexen 1975; Grigoriou 2000; Han *et al*. 2001). Soy proteins have also been used as a replacement for UF to produce experimental panels in various studies (Kuo *et al.* 1998; Clay *et al.* 1999; Mo *et al.* 2001; Liu *et al.* 2004).

As mentioned previously, the layer of wax and silica on the surface of the straw creates problems for achieving good bonding with adhesives (Schmidt *et al.* 2002). However, recent studies have revealed that bonding quality can be improved by treating straw with different chemicals and enzymatic methods that enhance surface wettability and increase the surface free radical concentration (Rowell *et al.* 1997; Loxton and Hague 1996; Gomez-Bueso *et al.* 2000; Karr and Sun 2000; Han *et al.* 2001; Schmidt *et al.* 2002; Zhang *et al*. 2003; Li *et al.* 2011).

Currently, there is little information on the properties of UF-bonded wheat straw particleboard panels manufactured using acetic anhydride and steam-treated raw materials. Therefore, the objective of this study was to evaluate both the physical and mechanical properties of experimental panels made from wheat straw treated with anhydride and steam to determine the effects of these treatments. Data from this work will provide initial information for the production of wheat straw particleboard with acceptable properties so that this underutilized waste resource can be converted into a value-added panel product.

EXPERIMENTAL

Materials and Methods

Commercially produced softwood particles of Scots pine (*Pinus sylvestris*) and wheat straw supplied by a local producer were used to manufacture experimental panels. The wheat straw was first chipped into 10 to 15 mm long pieces and then reduced to particles with 3 to 5 mm length using a laboratory hammermill. Pine chips were also reduced using the same hammermill into 3 to 5 mm long particles. Both wheat straw and wood particles were dried to 4% moisture content in an oven. Wood particles were used as they were supplied by the mill. Wheat straw particles were treated using one of four processes, namely soaking in a 9% acetic anhydride solution, boiling in a soapy solution of 20% concentration, boiling in water, or steaming at a temperature of 100 ºC. Particles were exposed to their respective treatment for 45 min. Following treatment, the raw material was redried to 4% moisture content in an oven. A mixture of 60% wood particles and 40% treated wheat straw was homogenously mixed before being sprayed with 14% urea formaldehyde adhesive with a solids content of 65% based on the oven-dry weight of the furnish. Ammonium chloride (NH_4Cl) solution with a concentration of 20% was also added to the panels at a rate of 1% as a hardener. Three single-layer panels with dimensions of 300 × 300 mm and a thickness of 19 mm were manufactured for each treatment at a density of 0.65 g/cm^3. Panels with no treatment were also manufactured as control samples.

Manually formed mats were compressed in a computer-controlled press using a temperature of 170 ºC and pressure of 2.2 MPa for 6 min. Following pressing, the panels were conditioned in a climate chamber at a temperature of 20 ºC and a relative humidity of 65% until they reached equilibrium moisture content. Samples were prepared based on European Standards (EN 310 1993; EN 319 1993; EN 317 1993) to evaluate bending, internal bond strength, thickness swelling, and water absorption of the panels. Table 1 displays the experimental schedule.

Table 1. Type and Condition of Straw Pretreatment

Group	Pretreatment
A	Control (non-treated straw particles)
B	Soaking in 9% acetic anhydride solution
C	Boiling in soapy solution
D	Boiling in water
E	Steaming at a temperature of 100 ºC

Data from the physical and mechanical tests are expressed as the mean ± standard deviation and were analyzed using analysis of variance (ANOVA) for a completely randomized design. Differences were considered statistically significant at $p \leq 0.05$.

RESULTS AND DISCUSSION

The physical and mechanical properties of the samples are displayed in Table 2. Panel type B, made from the raw material soaked in 9% acetic anhydride solution, resulted in the highest modulus of rupture value of 13.14 MPa, followed by panel type C.

Table 2. Characteristics of Particleboard Panels Made from Straw

Property	Non-treated Straw Particles (A)	Types and Condition of Pretreatment of Raw Material			
		Soaking in 9% Acetic Anhydride Solution (B)	Boiling in Soapy Solution (C)	Boiling in Water (D)	Steaming at 100 °C (E)
Bending strength (MPa)	5.58 a (0.61)* *10*	13.14 b (0.31) *10*	12.89 b (0.25) *10*	10.02 c (0.36) *10*	8.24 d (0.31) *10*
Internal bond strength (MPa)	0.11 a (0.01) *10*	0.21 b (0.01) *10*	0.30 c (0.02) *10*	0.18 d (0.01) *10*	0.15 e (0.02) *10*
Water absorption (%)	71.63 a (7.38) *10*	64.59 b (3.81) *10*	65.68 b (4.52) *10*	68.21 b (3.64) *10*	63.41 b (4.99) *10*
Thickness swelling (%)	40.89 a (1.62) *10*	23.29 b (1.78) *10*	27.04 c (2.48) *10*	27.47 c (1.71) *10*	30.70 d (1.57) *10*

(*) Values in parentheses are standard deviations.
Italic values indicate the number of samples used in each test.
a, b, c Groups with the same letter in each row were not statistically different ($p < 0.05$) according to a Duncan's multiple range test.

Both types of panels made from particles steamed or boiled in water also showed increased bending strength values as compared with that of control samples. All treatments of the raw material enhanced the bending properties of the samples, which could possibly be related to the dissolution of silica in the raw material during the exposure to such conditions. Reduction of silica in the particles would result in better bending quality and uniform distribution of the adhesive on the particles.

The internal bond (IB) strength of the samples also followed a similar trend, having a positive influence as a result of the four types of treatments. The control samples had the lowest IB strength value of 0.11 MPa, while the bond strength increased sequentially due to the treatments, as displayed in Table 2. Based on EN standards, the minimum bending strength and internal bond strength values are 11.5 MPa and 0.24 MPa, respectively (EN 312 2003).

It appears that the control panels and those made from raw material exposed to steam and boiling in water did not satisfy the bending requirements, while panel type B and panel type C did meet the EN 312 standards (EN 312 2003). However internal bond strength values of the panels met such requirements with the exception of panel type-C (EN 312 2003).

None of the samples had satisfactory thickness swelling values to meet 14%, which is stated as the minimum thickness swelling value for particleboard for general purposes (EN 312 2003). No wax or any other types of hydrophobic additives was used in the panels. If 1% or 2% wax had been added into the particles, their dimensional stability might possibly have been enhanced.

Figures 1, 2, 3, and 4 also illustrate the relative mechanical and physical characteristics of the samples. Values determined for the control samples were considered to be one, and the effect of each treatment was adjusted based on this.

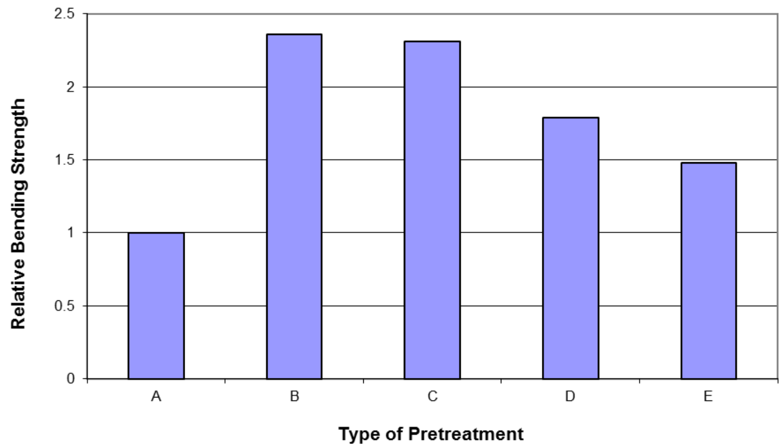

Fig. 1. Effects of different pretreatments on the bending strength of wheat straw particleboards

Fig. 2. Effects of different pretreatments on the internal bonds in wheat straw particleboards

Fig. 3. Effects of different pretreatments on water absorption by wheat straw particleboards

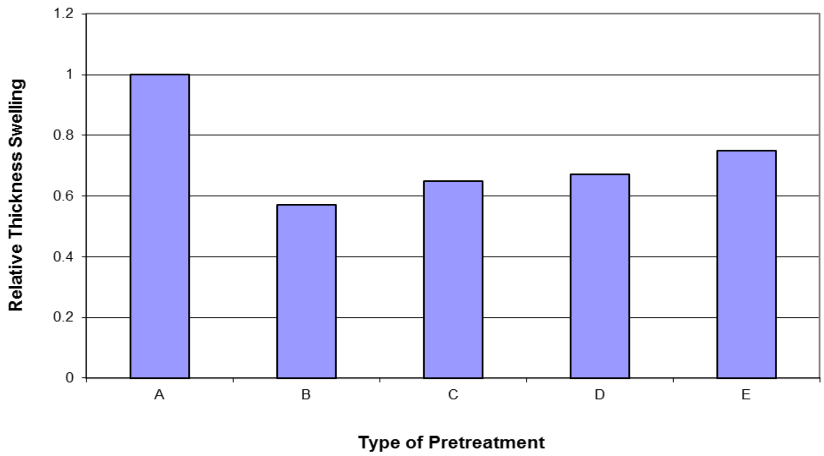

Fig. 4. Effects of different pretreatments on the thickness swelling of wheat straw particleboards

The pretreatment of straw particles with a chemical agent, such as acetic anhydride or a soapy solution, was found to be more effective at improving the physical and mechanical properties of particleboards than pretreatments involving steam or boiling in water. It appears that the pretreatment of straw particles by boiling in a soapy solution was the most effective method for increasing the internal bond strength of the samples. This can be explained by the improved wettability of the wheat straw surface and the subsequent improvement in adherence between the UF resin and the hydroxyl groups of cellulose. The strong effect of the soapy solution on the internal bonds in particleboards was attributable to the presence of surface-active agents in the solution, which improved wettability.

Similar conclusions were drawn in previous studies that examined the effects of using different types of agricultural waste as raw materials on the physical and mechanical properties of wood composite panels (Hashim *et al*. 2010; Luo and Yang 2010; Zhang *et al.* 2011; Akgül *et al.* 2012, 2013).

CONCLUSIONS

1. The pretreatment of wheat straw improved both thickness swelling, internal bond strength, and bending strength of experimental particleboards.
2. Samples manufactured from pretreated straw with acetic anhydride and soapy solution increased their internal bond strength by 2 and 3 times, respectively.
3. The pretreatment of wheat straw had a greater effect on the thickness swelling of boards than on water absorption. The pretreatment of wheat straw resulted in boards with 1.06 to 1.14 times lower water absorption and 1.33 to 1.75 times lower thickness swelling compared with the control boards.
4. The overall properties of particleboard panels made from treated straw were improved, which could be attributed to the removal of wax-like substances from the straw surface and to the enhancement of surface wettability. The results of this study indicate that wheat straw has the potential to be used as a raw material for manu-facturing particleboard panels.

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