Evaluation of cattail (Typha spp.) for manufacturing composite panels

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A R T I C L E   I N F O

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A B S T R A C T

Cattail (Typha latifolia or Typha angustifolia) is a perennial herbaceous plant that belongs to Typhaceae family. In the U.S., it is widely seen invading marshes, pond, lake, river and drainage ditches thus impeding water flow and increased siltation. A study was conducted to evaluate the application of cattail as potential cellulosic raw material for the manufacturing of commercial composite panels (particleboards). Particleboards of low density (0.48 g/cm³) were prepared using hot press and by varying the proportion of cattail and wheat straw and mixing with 3% methylene diphenyl diisocyanate (pMDI). The density, particle size distribution, water absorption, internal bond strength and flexural properties were measured on the resulting particleboards. The results of the experiment showed that a blend of 75% cattail and 25% wheat straw particles exhibited superior average mechanical properties for application in the particleboards. Overall the mixed blends performed better than the control 100% wheat straw or cattail in flexural stiffness, flexural strength, internal bond and water absorption tests.

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1. Introduction

Wood particles have been the preferred raw material for manufacturing medium and high density particleboards, however, in the last decade the search for alternative cellulosic materials has gained significant momentum. Some of the factors driving the search for non-wood fibers includes wood shortage, legislative provisions, end-of-life-cycle recycling mandates, cellulosic ethanol and low cost of non-wood fibers. Environmental awareness and corporate social responsibility have also prompted many industries, particularly in high income countries, to consider more sustainable materials as their raw material feedstocks. Industries are now increasingly looking at natural inputs in a more positive and proactive manner. Natural feedstocks are now considered technically valid contributing to premium-pricing of final products, environmental attributes, and promoting socially responsible production and disposal requisites.

In particleboards domain many studies have already been conducted to replace wood particles by crop based agricultural residues such as wheat straw (Mo et al., 2003), rice straw (Li et al., 2010), cotton gin (Holt et al., 2009), peanut hulls (Guler et al., 2008), maize husks and cobs (Evon et al., 2010) bagasse fibers, (Ashori and Nourbakhsh, 2009), and sunflower seed husks (Cosereanu et al., 2015). Recently some specific studies has also been done on particleboard from Kenaf (Juliana et al., 2012) and wheat straw (Zhang et al., 2011).

Cattail (Typha latifolia or Typha angustifolia) is a perennial herbaceous plant that belongs to Typhaceae family. In the U.S., it is widely seen growing on marshes, ponds, lakes and rivers. It is considered to be dominant competitor in wetlands and in many areas it can reach heights from 3 to 10 feet. The leaves look like giant blades of grass, about one inch wide. In upper Midwest plains of U.S., cattails are invading farm ponds, irrigation canals and drainage ditches thus impeding water flow and increased siltation (Mitchell et al., 2011). There is a considerable scope for developing commercial opportunities for lesser-known natural products, for example fibers from developing countries. The natural fiber crops are of vital importance to the livelihood and food security of farmers in some of the poorer regions of the world. As renewable raw materials, they require little if any chemical or other production inputs. A few studies have recently reported the potential of cattails for making insulation boards (Luakanchanaphana et al., 2012; Krus et al., 2014). To our knowledge, the use of cattail for any commercial product has not been fully evaluated. This is the first study to evaluate the feasibility of cattails for manufacturing particleboards for commercial applications. This research can lead to application of cattails as a potential cellulosic material for manufacturing composite boards of varying densities that can be used in construction, packaging and light weight composites. It is assumed cattail particleboards
could be used in the same applications that wood based in low-end furniture, doors cores, sheathing panels and other indoor building projects.

The main objective of this research was to evaluate the feasibility of cattail as an alternate cellulosic raw material for use in manufacturing commercial composition panels (particleboards). An investigation was conducted to evaluate and compare the physical and mechanical properties of particleboards made using a combination of cattail and wheat straw particles.

2. Materials and method

The low density (0.48 g/cm³) particleboards were prepared by varying the proportion of cattail and wheat straw and mixing up with poly methylene diphenyl diisocyanate (pMDI) resin at 3%. Previous research has shown pMDI is best suited resin for straw composites (Mo et al., 2003).

2.1. Materials

The cattail material (Typha spp.) was manually harvested in 2013 winter from the South Western region of North Dakota. The cattails with stem and leaves were cut to a length of approximately 50–60 cm and tied into bundles before storing them in jute bags. Dried and preprocessed wheat straw particles were obtained from commercial processing. The wheat straw was hammermilled, refined, sized prior to drying at the commercial facility. Over 92% of wheat straw particles showed fiber length greater than 0.25 mm. MDI resin from Huntsman LLC (Geismar, TX, USA) was used as resin to bond the particles. The amount of resin in all the particleboard compositions was kept constant at 3% on weight basis. A silicone based release agent was sprayed on the surface of platens to prevent adhesion of the boards to platens.

2.2. Material preparation

The cattail bundles were stored and dried in a room under ambient temperature at 22 °C and relative humidity 65% for 60 days. Dried cattail stems were cut into 25 cm sections for feeding into a particle sizing machine. A Thomas Model 4 Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) fitted with 5 mm screens was used to fractionate the material. Wheat straw was used as received from the supplier. The particle size distribution of the particles used to manufacture the particleboards was determined using standard ASTM sieves as a guide. Particle size distributions were found by using four different mesh sizes – >20 mesh, >60 mesh, >100 mesh, and 100+ mesh. Approximately 8% of the cattail fibers were rejected during screening. The cleaned and sized material was oven dried to achieve a moisture content of 8–9%. Dried material was transferred into the rotary drum fitted with paddle mixers. To ensure uniform distribution of resin, an atomized air gun was used to spray the resin on the particles while they were rotating in the drum.

2.3. Board manufacturing

The particle boards were manufactured using a bench top manually operated laboratory hydraulic hot press, Model 4386, with 30 ton capacity and fitted with preset controls (Carver Inc., Wabash, IN). The processing conditions are shown in Table 1. The resinated cattail and wheat straw material was manually transferred to aluminum mold (lab-made) installed on platens measuring 30.5 × 30.5 cm² and then pressed into particleboard at 190 °C temperature, 1.54 MPa platen pressure and 420 s press closure time. The aluminum mold set had a constant gap of 0.63 cm that allowed the final particleboard to have a thickness of 1.25 cm and a density of 0.48 g/cm³. Four formulations of particleboards with cattail content of 100%, 50%, and 25% by weight and remaining wheat straw and a control with 100% wheat straw particles were manufactured. A band saw was used to cut down the boards into appropriate size for testing as recommended in ASTM Standard D1037-12. Moisture content of resinated straw was determined by oven method at 105 °C for 12 h.

2.4. Particleboard properties evaluation

The physical and mechanical properties of the particleboards were analyzed following the guidelines described in ASTM D1037 standard – 06a Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials (ASTM, 2012). All the test samples were preconditioned at 65% relative humidity at 23 °C for 48 h.

For density determination, length, width and thickness of each specimen were measured with a digital caliper (CD-8" C, Mitutoyo Co., Japan). The density was determined by dividing the particleboard mass (g, wet base) by its volume (cm³). The target density of the panels manufactured in this study was 0.48 g/cm³. Typically the density of straw particleboard can be controlled to meet application requirements: density lower than 0.59 g/cm³ for insulation, packaging, core materials; 0.59–0.80 g/cm³ for kitchen cabinet, countertop and floor; 0.8–1.0 g/cm³, for furniture, deck top and shelf board.

The water absorption of the particleboards was calculated using square samples measuring 15.2 × 15.2 cm² in length and width. A water bath was used to immerse samples. The water temperature was kept constant at 22 °C in order to calculate the amount of water absorbed and the swelling thickness of the boards. Three specimens of each formulation were soaked in a water bath tap water for 2 h. The weight changes in the samples before and after soaking were calculated.

Modulus of elasticity (MOE) and modulus of rupture (MOR) were obtained from three-point bending test. Particleboards were cut into rectangle pieces measuring of 5 × 20.3 cm². Six specimens were prepared for each formulation for three-point bending tests. For internal bond tests, square samples measuring 5 × 5 cm² were cut and glued to metal blocks using hotmelt adhesive. Flexural tests were conducted on Universal Testing System Instron Model 5567 (Instron Corp., Norwood, MA, USA).

2.5. Statistical analysis

Analysis of variance (ANOVA) tests were performed using Minitab 16 Statistical Software on several of the data sets shown (Minitab, 2014). Mean comparison tests were also performed to establish the exact statistical significance between the four treatments. Both Duncan and Fisher’s test were performed, with Fisher’s test being the criteria for grouping similar formulations together. Within an experiment a formulation with different letter indicates a significant difference at α = 0.05.
3. Results and discussion

The test results showed that cattail fibers can be used to manufacture particleboards. However, the cattails required additional drying time and hammer-milling processing for matching the moisture content and particle size of the wheat straw.

3.1. Particle size distribution

Fig. 1 shows the particle size distribution of two materials. Over 93% of particles were retained over 60 mesh screen. The particle size distribution of cattail fibers was slightly different from wheat straw with former exhibiting higher concentration of bigger particle sizes. Overall wheat straw particles were slightly smaller and had higher percentage of small particles. The suitability of straw materials for particleboard production can be explained by fiber length, cellulose content, and portion of lumen. Technologically valuable fibers are long, thick in cell wall, rich in cellulose, and low in lumen.

When comparing straw stalk with either softwoods or hardwoods, as shown in Table 2, the former emerges technologically inferior (Akgul and Tozluoglu, 2009; Ververis et al., 2004).

3.2. Impact of material types on water absorption

The untreated cellulosic fibers have typically strong affinity to moisture. Previous studies have highlighted the weakness of the cellulosic materials for water absorption in commercial products (Holt et al., 2014). High values for water absorption (WA) are undesirable since they can lead to dimensional instability and cause potential issues such as bowing, cupping, swelling in the products made from cellulosic materials.

As shown in Fig. 2 (Two-hour WA and TS) the cattail fibers helped to reduce the WA in the particleboards. The formulation with 25% cattails and 75% wheat straw showed the lowest WA of 20.2% followed by a 50:50 blend with 20.5%. The control 100% wheat straw and cattails particle boards showed highest WA of 32% and 23.4%, respectively. The results are similar to some of the previously reported studies (Xu et al., 2009). The cattails particle exhibited lower thickness swelling as compared to wheat straw particles. Overall the blends containing cattail and wheat straw fibers generated lower WA values which can be explained through the particle size distribution of materials. The smaller wheat straw particles occupied the open spaces in between the long and wide particles therefore restricting the flow of water into the cavities and voids. The increased WA value of 100% cattail particleboards can be attributed to loose packing density of randomly organized long particles whereas poor bonding between wheat straw particles due to presence of cuticular layer may have resulted in higher WA.

3.3. Impact of fiber types on the flexural properties of particleboards

Flexural properties of particleboards are important for determining appropriate application and necessary certification. Although, they are used primarily in nonstructural applications in which strength properties are not critical they can impact the overall the performance of the product. The mean values of flexural properties calculated during the static bending for the five different formulations are presented graphically in Figs 3–4 for the comparison of the effects of different material formulations on the particleboard properties. Generally, board properties improve with increasing fiber or particle length (aspect ratio) and it is obvious that particleboard containing longer particles showed higher flexural properties. Mixed effects of both particles can be observed when comparing the properties of the blended formulations against 100% cattail or wheat straw particleboards.

It is well known the aspect ratio of fibers can have significant effect on the strength properties of fiber reinforced composites. In this study a similar relationship was observed, formulation with 75% cattails and 25% wheat straw showed highest MOE (17.95 MPa) followed by formulation with 25% cattails and 75% wheat straw. Particleboards with 100% wheat exhibited lowest MOE (3.45 MPa) and this can be attributed to weak bonding between wheat straw particles due to presence of cuticular waxy layer. The negative effect of inorganic silica in wheat straw has been reported in a previous study (Mo et al., 2003; Zhao et al., 2014). Effective particle conformation between the particles of mixed fiber blends helped

<table>
<thead>
<tr>
<th>Material type</th>
<th>Fiber length (mm)</th>
<th>Fiber width (μm)</th>
<th>Lumen (μm)</th>
<th>Ash content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwoods</td>
<td>2–5</td>
<td>22–45</td>
<td>15–28</td>
<td>0–1</td>
</tr>
<tr>
<td>Hardwoods</td>
<td>0.8–1.6</td>
<td>15–24</td>
<td>7–15</td>
<td>0–1</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.7–1.2</td>
<td>13.2–13.6</td>
<td>4.2–5.7</td>
<td>4.5–9.0</td>
</tr>
<tr>
<td>Non-wood fibers</td>
<td>0.7–2.3</td>
<td>13–22</td>
<td>5.8–13</td>
<td>5.5–7.6</td>
</tr>
</tbody>
</table>
to reduce the voids, which helped the particleboard matrices to efficiently transfer stresses leading to higher MOE values.

A similar trend was observed for flexural strength. Flexural strength is an important property which determines the maximum load a material can take before failure occurs, and is important for particleboard users to define the maximum load conditions of their products. Generally, board properties improved with the addition of cattail fibers as shown in Fig. 4. Once again the highest flexural strength (446.3 N) was observed in particleboards with 75% cattail fibers and 25% wheat straw.

3.4. Impact of fiber types on internal bond strength

Internal bond (IB) strength is an important property in wood composite boards. It shows the bond strength between the particles. In general, higher IB values are preferred for particleboards. In another study, IB strength of particleboards with a similar density (0.78) and resin (3.5%) ranged between 0.51 and 0.57 N/mm² (Ye et al., 2007; Wang and Sun, 2002). The low density of the particleboards resulted in lower IB strength values; these values were expected due to presence of voids and loose packing of particles in the boards. The IB strength values of all the treatments are presented in Fig. 5. The formulations with 75% cattails and 25% wheat straw resulted in best IB strength values. The use of cattails at higher proportions resulted in superior IB value. This can also be related to the improved MOE and MOR values of the particleboards as seen earlier. Interestingly 100% cattail and a mixed formulation with 50% cattails showed the lowest IB strength. As discussed earlier, cuticular wax or inorganic silica coating on wheat straw may have been possible barriers to glue adhesion.
4. Conclusion

The results of the experiment showed that a blend of 75% cattails fibers and 25% wheat straw exhibited superior average mechanical properties for practical application in the particleboards. The mixed blends performed better than the control 100% wheat straw or cattails in flexural stiffness, flexural strength, internal bond and water absorption tests. It also showed lowest standard deviation as compared to the other formulations in the tests. The presence of cuticular waxy layer on wheat straw can impact the physical and mechanical properties of the particleboards. This study proved the advantage of using cattail fibers together with wheat straw for the production of particleboards and not the benefit of making panels 100% of cattail. Hence cattail can be used as an economically alternative raw material for manufacturing composition panels. Use of cattail for industrial products can result in controlling its invasive growth into the water bodies and as a renewable and environmentally friendly feedstock. Further research is needed to identify best methods to harvest and process cattails so it can be economically utilized.

References

Ministab 17, 2014. Ministab Statistical Software. State College PA, USA.