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Selected properties of particleboard panels manufactured from rice straws of different geometries

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ABSTRACT

The objective is to evaluate the primary mechanical and physical properties of particleboard made from hammer-milled rice straw particles of six different categories and two types of resins. The results show the performance of straw particleboards is highly dependent upon the straw particle size controlled by the opening size of the perforated plate inside the hammer-mill. The static bending and internal bonding strength of polymeric diphenylmethane diisocyanate (pMDI) resin-bonded boards initially increase then decrease with decreased particle size. The thickness swelling, water absorption, and linear expansion of particleboards decrease with increasing particle size. Compared with pMDI resin-bonded panels, the rice straw particleboard bonded using urea-formaldehyde resin exhibits much poorer performance. The optimized panel properties, obtained when using 4% pMDI and straw particles hammer milled with a 3.18 mm opening perforated plate, exceeded the M-2 specification of American National Standard for Wood Particleboard.

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1. Introduction

Rice is the primary food for more than 40% of the world's population, with about 596 million tons of rice and 570 million tons of rice straw produced annually in the world (Pathak et al., 2006; Mohdy et al., 2009). At present, most of these residues are burnt in situ after harvest. The field burning of rice straw and other agriculture residues in wide areas not only results in serious environment issues, but also wastes precious resources. Faced with worldwide shortages of forest resources, environmental pollution and waste of biological resources resulting from field burning of rice straw and other agriculture residues, there has recently been a revival of interest in using rice straw and other agriculture residues to produce building materials including composite panels (Zheng et al., 2007; Ye et al., 2007; Copur et al., 2008).

The properties of rice straw and other agro-residue fibers were reviewed by Rials and Wolcott (1997). Boquillon et al. (2004) found that the properties of wheat straw particleboards using urea-formaldehyde (UF) resins were poor, especially for internal bonding (IB) strength and thickness swelling (TS). Research conducted by Mobarak et al. (1982) showed that bending strength up to 130 N/mm^2 and water absorption as low as 10% could be obtained for bagasse panels produced at 25.5 MPa pressing pressure and 175 °C. Increasing the initial moisture content of pith from 7% to 14% resulted in deterioration of both strength and water resistance. Grigorious (1998) reported that straw was suitable for the production of good quality surface layers for particleboard if bonded with polymeric diphenylmethane diisocyanate (pMDI) resin or a combination of UF and pMDI. Yang et al. (2003) developed a sound absorbing composite from rice straw and wood particles, and confirmed that rice straw could partially substitute for wood particles up to 20% by weight without reducing the bending strength. Han et al. (1999, 2001) investigated the effect of silane coupling agent level and ethanol–benzene treatment on board properties and found that physical properties for both reed and wheat boards were improved. They also reported that bonding performance of UF resin-bonded reed and wheat straw fiberboards could be improved if the fiber was pre-treated under different steam cooking conditions in the refining process. All properties of medium-density fiberboard (MDF) made from the treated reed and wheat straws, except the thickness swelling, could meet Japanese Industrial Standard for Fiberboard (JIS A5905, 1994). In addition to the steam treatment, enzyme pretreatment of wheat straw was also an effective way to improve the bonding performance (Zhang et al., 2003). To reduce the manufacturing cost, some alternative resin systems were used to make biomass based composite panels. Soy protein isolate modified by 10% pMDI was used to make low density straw-protein particleboard and excellent compression

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and tensile strengths were observed (Mo et al., 2001). Interest in using rice straw mixed with low quality bamboo or other bio-based residues to produce composite panels has increased recently (Hiziroglu et al., 2008; Lee et al., 2006).

Some researchers have succeeded in developing substitutes for wood particles using agriculture residues including rice straw, but producing rice straw boards with performance rivaling wood-based boards at lower production cost utilizing a simpler process is still the main challenge to be addressed on a global scale. Compared with wooden material, rice straw contains a high amount of ash and silica (Pan et al., 1999; Pan and Sano, 2000; Hammerr et al., 2001), which results in weak bonding between particles and very low internal bonding strength within panels. Moreover, rice straw stems are hollow and tubular structures. When the straw is cut into small particles, some of the particles cannot be split and they maintain a tubular shape, which prevents the resin from reaching internal surfaces of the straw. In order to have favorable internal bonding strength within rice straw particleboard, it is crucial that most of the straw be split to allow uniform resin distribution on both inner and outer straw surfaces. A hammer mill, which is a typical tool for manufacturing wood-based particleboard panels, was found in our previous trial to be effective at breaking down the rice straw. The opening size of perforated metal plates in the hammer mill to control the geometry of straw particles was closely related to the percentage of split rice straws. The main objective of this project is to explore the technical feasibility of manufacturing composite panels from hammer-milled rice straw particles, and to evaluate some mechanical and physical properties of particleboard as affected by various particle sizes and adhesive types.

2. Methods

Rice straw was obtained from California, United States. Its variety number was Calrose M-206. It was approximately 1 m tall at harvest and cut above the water line leaving the lower third as stubble in the field. This rice was also harvested with a conventional straw walker combine rather than a rotary, which optimizes straw quality by retaining much longer sections of stalks for bailing. The average moisture content of the straw was about 8.1%. After received, the rice straw was broken down into different sizes using a hammer mill. Six different perforated metal plates with opening size of 25.40 mm (1 in.), 19.05 mm (3/4 in.), 12.70 mm (1/2 in.), 6.35 mm (1/4 in.), 3.18 mm (1/8 in.) and 1.59 mm (1/16 in.) were used for processing the rice straw. Screen analysis was also conducted on each particle type using six different sieves.

After hammer milling, a fair amount of rice granules (about 1.4% of total weight) were noticed which were later removed from rice straw particles by the winnowing method. Ten grams rice straw particles from each opening size were randomly chosen and un-split straw particles were visually identified and separated to estimate the percentage of un-split straw particles. The particles for the fabrication of UF-bonded panels were oven-dried at 100 °C to 2–3% moisture content and the particles for the fabrication of pMDI-bonded panel were kept at their previous moisture contents (7.0–9.0%) prior to the resin applications.

The commercial pMDI and UF resins used in this study were acquired from Huntsman International (286 Mantua Grove Rd., West Deptford, NJ, USA) and Arclin Corporation (281 Wallace Road, North Bay, Ontario, Canada), respectively. The UF resin was water dispersed with a solid content of 65%. The resins were sprayed onto the rice straw particles in a rotating drum blender. A resin content of 4% (oven-dried weight basis) was used for pMDI-bonded boards, and 12% or 16% were used for UF-bonded boards. A 91.4-by 91.4-cm Nordberg hot press with a PressMAN Press Control system (Alberta Research Center, Alberta, Canada) was used to manufacture the boards and the platen temperature was 180 °C for manufacturing pMDI-bonded boards and 170 °C for UF-bonded boards. The dimension of the boards made in this study was 559 by 559 mm (22 by 22 in.) with thickness of 12.5 mm (0.5 in.). The target density was 0.70 g/cm^3. Longer hot press time was used to ensure the full cure of resin with 350 s (40 s closing, 260 s at the target thickness, and 50 s opening) for pMDI resin and 510 s (100 s closing, 320 s at the target thickness, and 90 s opening) for UF resin. Two replicate boards were made at each condition.

The modulus of elasticity (MOE), modulus of rupture (MOR), linear expansion (LE), TS, water absorption (WA) and IB of the samples were prepared and tested in accordance with American standard test methods for evaluating properties of wood base fiber and particle panel material (ASTM D 1037-06a). Each measurement presented herein is the average for six samples cut from two different boards. Static bending and IB values were measured using an MTS (Material Testing System 634.11F-24) and universal testing machine (Instron 555). The TS and WA were measured after 24-h immersion in distilled water at 20 °C.

3. Results and discussion

Six different perforated metal plates were used for processing rice straw with opening sizes of 25.40 mm (1 in.), 19.05 mm (3/4 in.), 12.70 mm (1/2 in.), 6.35 mm (1/4 in.), 3.18 mm (1/8 in.) or 1.59 mm (1/16 in.). Basically, six categories of rice straw particles using the six different perforated metal plates in the hammer mill were prepared in this study. The distribution of particle size of the six types of rice straws varied considerably. Table 1 summarizes the distribution of particle size based on mesh analysis. The largest mass fraction remained on 3, 3, 16, 20, 35 and 35 mesh sizes when the opening size in the perforated metal plates was 25.40, 19.05 12.70, 6.35, 3.18 and 1.59 mm, respectively. With the decrease of the perforated metal opening size, the mass ratio of particles which passed through a sieve of larger dimension decreased, and that of particles which passed through a sieve of smaller dimension increased. The un-split hollow stems appeared considerably when the dimension of the opening size was greater than 6.35 mm. The percentages of un-split straw particles were 1.3%, 4.4%, 9.7% and 17.4% when the opening size were 6.35, 12.70, 19.02 and 25.40 mm, respectively. The presence of un-split straw particles in the mat significantly decreases the IB strength of boards and increases the variability because of the lack of resin distribution to the internal surfaces of un-split particles. It is also observed that when the opening size of the perforated metal plates inside the hammer mill is less than 3.18 mm, the rice straw particles can be thoroughly split in the hammer mill and effect of the un-split particles on the bonding strength is negligible (Fig. 1).

It was well known that board density is one of the important factors that affect mechanical properties of particleboard. In our

Table 1
Distribution of particle prepared with different sieve opening size based on mesh analysis.

Mesh size	Mass ratio (%)					
	D = 25.40	*D* = 19.05	*D* = 12.70	*D* = 6.35	*D* = 3.18	*D* = 1.59
⩽3	33.33	23.15	2.14	0.00	0.00	0.00
3–9	9.43	12.97	20.53	1.38	0.00	0.00
9–16	11.55	16.35	23.62	17.20	1.62	0.00
16–20	13.57	16.90	18.87	28.57	20.65	2.96
20–35	15.87	15.69	17.87	26.18	34.63	43.15
35–60	9.99	8.48	10.03	14.27	23.26	30.06
⩾60	6.26	6.46	6.94	12.39	19.84	23.83

D denotes the diameter of sieve opening in perforated metal plate, mm.
Distribution is expressed as percentages based on the total weight.

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