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Properties of medium density fiberboards made from renewable biomass

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Abstract

The goal of this study was to determine the comparative properties of dry-formed medium density fiberboards (MDF) made from renewable biomass (wheat and soybean straw) and those from conventional soft wood fiber. The MDF properties evaluated were modulus of elasticity, modulus of rupture, internal bond strength, thickness swell, and screw holding capacity. The results show that MDF made from wheat straw fiber and soy straw fiber have weaker mechanical and water resistance properties than those made from softwood fiber. Soybean straw is comparable to wheat straw in terms of both mechanical and water resistance properties to make MDF. Water resistance of MDF decreased drastically with increasing straw fiber composition. Wheat straw fiber and soybean straw fiber should be physically or chemically treated to increase their water resistance property for MDF production.

Keywords: Ag-fiber; Wheat straw; Soybean straw; Fiberboard property; Water resistance

1. Introduction

Fiberboard—structural and decorative—is a fibrous-felted, homogeneous panel made from lignocellulosic fibers, combined with a synthetic resin or other suitable bonding system, and then bonded together under heat and pressure (ANSI Standards, 1994). Additives may be introduced during manufacturing to improve certain properties. Fiberboards are classified by density. A fiberboard with specific gravity between 0.50 and 0.80 (density between 31 and 50 lb/ft^3) is classified as medium density fiberboard (MDF) and a fiberboard with specific gravity greater than 0.80 (density greater than 50 lb/ft^3) is classified as hardboard (ASTM Standards D1554-1986). Fiberboards are manufactured primarily for use as panels, insulation, and cover materials in buildings and construction where flat sheets of moderate strength are required. The furniture industry is by far the dominant fiberboard market. They are also used to a considerable extent as components in doors, cabinets, cupboards, and millwork (FAO, 1958). Fiberboard frequently takes the place of solid wood, plywood, and particleboard for many furniture applications. Comparing to particleboard, overlaying with sheet materials and veneering, fiberboard has tight edges that need not be banded and can be routed and molded like solid wood (Seidl, 1966). The potential use of fiberboard in other interior and exterior markets such as moldings, exterior trim, and pallet decking has been explored by the industry and the market for fiberboard is fast expanding. The forest products industry in North American traditionally uses sawmill residues and small round logs as raw materials to manufacture fiberboard. However, growing concern about the environment has led to changes of forest management practices, resulting in significant reduction in wood harvest from our national forests in the midst of growing demands. Increasing import of timber and fiber supply is only a temporary solution. We must consider the prospects for developing new feedstock sources for fiberboard production. There is a clear potential for the use of agricultural fiber

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in manufacturing what have traditionally been wood-based products (Bowyer, 1995; Clancy-Hepturn, 1998). It has been estimated that 400 million dry tons of crop residues are annually produced in the United States (DOE, 2003). The literature review by Youngquist and co-workers (Youngquist et al., 1994) cited 1165 research reports worldwide on use of non-wood plant fibers for building materials and panel products from 1913 to 1993. Only two papers reported the use of soybean straw as raw material. Wheat straw particle composites have already established a niche market in the composite products (Anderson, 1995). The use of agricultural fiber for pulp and panel composite materials is commonplace in many parts of the world, but relatively rare in North America. The North American trend, however, seems to be reversing. Since 1995, there has been a proliferation of new manufacturing facilities in Canada and US to produce composite panels from agricultural residues. Most of these manufacturing plants produce particleboard from wheat straw, but soybean stover has not been considered. Because they contain cutin, a waxy substance, straw particles cannot be bonded with conventional adhesives such as urea–formaldehyde (UF) or phenol–formaldehyde (PF). Currently, isocyanate-based adhesives, such as polymeric diphenylmethane diisocyanate (MDI), are exclusively used to bind straw particleboards. MDI is much more expensive than the conventional PF or UF resin. Whether we can make fiberboard from renewable biomass using conventional UF resin is one question addressed in this study.

The objectives of this study were to produce MDF from wheat and soybean straws and investigate the comparative mechanical and water resistance properties of MDF made from soybean straw fiber, wheat straw fiber, and soft wood fiber, which were bonded with conventional urea–formaldehyde resin.

2. Methods

2.1. Experimental design and materials

The experimental design was a factorial arrangement of treatments conducted in a completely randomized block design with sampling and subsampling. The outline of the experimental design is presented in Table 1. Eighteen treatments were formulated as:

Table 1
Experimental design

Factors	Factor values	Block (repetition)	Sample	Subsample
Adhesive level	6%, 9%, 12%			
Ag-fiber type	Soy straw, wheat straw	2	2	2
Wood fiber/ ag-fiber composition (%)	100/0, 50/50, 0/100			

$$\text{Treatments} = 3 \text{ adhesive level} \times 2 \text{ ag-fiber type} \times 3 \text{ fiber composition}$$

Two batches (blocks) of MDF were produced for each treatment and two fiberboards (samples) were made for each batch. A total of 72 MDFs were produced for this research. Two subsamples were taken from each board for each property evaluated.

A conventional urea–formaldehyde adhesive (WC-10) was obtained from Borden Chemical, Inc. (Columbus, Ohio). The adhesive levels were set at 6%, 9%, and 12%, expressed as a percentage of adhesive solid weight based on the oven-dried fiber weight. The adhesive level range extended slightly higher and lower than the levels used in the industry.

A pressure-refined industrial fiberboard furnish consisting of pure Ponderosa pine softwood fiber was obtained from Pella Inc. (Pella, Iowa) and used as control fiber source. The dry-basis moisture content of the softwood furnish was 3.26%. Fibers from biomass were processed at the Center for Crop Utilization Research, Iowa State University. The raw straw was hammer-milled then soaked in tap water overnight. The soaked straw was then fiberized (pulped) by using an atmospheric Sprout-Bauer refiner with directional plates (Model 12 D.M. Sprout-Bauer Inc.). Fiberization of wheat straw and soybean straw at atmospheric pressure was carried out by passing the damp milled straw along with hot running water at 60 °C through the Sprout-Bauer refiner's rotating plates. The plates were set 0.127 mm (0.005 in.) apart. The pulps were collected, pre-dried, and preconditioned by passing through an electric vacuum blower (AirStream-II, McCulloch Corporation, Tucson, AZ) to break up fiber agglomeration. The drying process was completed in a convective oven, and then the final moisture content of the fibers was determined. The dry-basis moisture content of the ag-fibers ranged from 3.85% to 11.3%. The wood fiber was the control to compare with different compositions of wood fiber/ag-fiber, expressed as percentage of oven-dried fiber weight and formulated at compositions of 100/0, 50/50, and 0/100.

2.2. MDF production

Enough fiber furnishes to make two 250 mm × 350 mm × 12.5 mm thick (10 in. × 14 in. × 1/2 in.) MDF boards at a target specific gravity of 0.75 was weighed and placed into a drum blend. While being tumbled in the rotating drum blend, the furnish was first sprayed with 1% wax emulsion (EW 403H, Borden Chemical Inc., Columbus, Ohio) based on dry fiber weight as sizing to reduce water absorption, followed by spraying an appropriate level of urea–formaldehyde resin depending on the treatment. The atomizing air pressure and the liquid pressure for urea–formaldehyde resin were 240 kPa (35 psi) and 140 kPa (20 psi) respectively. Minor agglomeration of fibers was observed.

A pre-calculated amount of furnish was then hand-felted into a 250 mm × 350 mm (10 in. × 14 in.) forming