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The mechanical properties of soybean straw and wheat straw blended medium density fiberboards made with methylene diphenyl diisocyanate binder

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ABSTRACT

A study was conducted to test the mechanical properties of medium density fiberboard (MDF) produced using soybean straw [Glycine max], wheat straw [*Triticum aestivum*], and a blend of the two fibers and the variations in properties that this blend produced. Additionally, the difference of soybean straw fibers compared to wheat straw fibers in the performance of MDF properties was investigated. Three formulations of the fibers were produced and tested to investigate the variation between properties of boards produced from the different fibers. The boards produced for testing were pressed using a hot press with 4 wt% methylene diphenyl diisocyanate (MDI) resin used to bond the particles and 2 wt% AW-50 wax emulsion used as a water retardant. The boards produced had a nominal density ranging from 579 kg/m^3 to 646 kg/m^3. Several test methods from ASTM standard D1037-12 were utilized to test the physical and mechanical properties of the boards. Initial results from the testing showed that several combinations of fibers could be used to produce boards with mostly no statistically significant difference between any one formulation, the only difference being a significantly higher difference in the screw withdrawal load needed for 100% wheat fiberboards compared to other formulations. The testing showed the viability of soybean stover fibers as a viable substitute or blend with wheat straw fibers with no appreciable decrease in the board properties except in the case of direct screw withdrawal resistance.

1. Introduction

Conventional medium density fiberboard (MDF) is composed of wood particles that have been pressed together under high temperature and pressure with a resin binder to form a homogeneous board. Medium density fiberboard is defined primarily by density, with various grade designations based on the mechanical and physical properties of the board. For MDF, the density of boards can range from 500 kg/m^3 to 1000 kg/m^3 (ASTM D1554-10, 2010). For the intent of this research, the produced fiberboard was designed to be within the range of 558 kg/m^3 to 682 kg/m^3 with a nominal density of 620 kg/m^3. This density range was chosen to reduce the total weight of the produced boards while retaining the boards' mechanical properties as much as possible. Conventional fiberboard is produced from woody biomass sources, but fiberboard can also be made and has been produced utilizing fiber sources from agricultural residuals with the lignocellulosic material from crops such as corn, rice, and wheat being utilized to produce fiberboard (Halvarsson et al., 2010; Reddy and Yang 2005). This use of agricultural residuals to create fiberboard is particularly notable for regions where sources of woody biomass is scarce or cost prohibitive to obtain and manufacture into fiberboard. One such region is the upper Midwest region of the United States, specifically North Dakota, where supplies of woody biomass and wood fiber are scarce, but supplies of crops that produce fibers viable for fiberboard production are abundant (NASS Report, 2013). The high production rate of these crops, notably soybean and wheat, and the comparable properties of crop fiber based fiberboard to conventional fiberboard motivate research on the viability of soybean straw medium density fiberboard (Ye et al., 2007). Aside from the advantage of using readily available agricultural residuals, fiberboard made from alternative biomass sources alleviates the demand on woody biomass, which is being utilized for other applications. Testing has been conducted on woody biomass to produce ethanol, as the cellulose can be converted to glucose and then fermented to produce ethanol (White, 2009). The demand for woody biomass should then increase in the future to account for

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Table 1
Fiberboard density for each formulation.

Sample formulation	Average density [kg/m^3]	Standard deviation	Coefficient of variation [%]	Standard error of the mean	Relative error [%]
100% Soybean	579	67.8	11.7	22.6	3.91
50/50% Soybean/wheat	584	59.2	10.2	19.7	3.38
100% Wheat	632	35.0	5.5	11.7	1.84

Table 2
Fiberboard thickness for each formulation.

Sample formulation	Average thickness [mm]	Standard deviation	Coefficient of variation [%]	Standard error of the mean	Relative error [%]
100% Soybean	10.47	0.854	8.16	0.228	2.18
50/50% Soybean/wheat	10.11	0.514	5.08	0.137	1.36
100% Wheat	13.06	1.227	9.40	0.328	2.51

higher demand in applications such as ethanol production and the conventional use of composite board production.

To provide alternatives to woody biomass and to ensure that multiple sources of biomass can be used for MDF production, a laboratory scale test of a single substrate fiber and blended fiber MDF composed of wheat straw and soybean straw was conducted. The research focus for this study was to evaluate the properties of fiberboard manufactured with a single fiber substrate as well as a blended fiber substrate. The performance of soybean straw fibers versus wheat straw fibers was also of interest.

2. Materials and methods

2.1. Material preparation

Raw wheat straw [*Triticum aestivum*] and soybean straw [*Glycine max*] was obtained from local farming operations and hammer milled by the Masonite Corporation's Wahpeton, ND facility. The hammer milling reduced the fiber size, and then the fibers were screened to remove fines and dust from the fiber stream. The fibers were then transported to North Dakota State University to perform the hot pressing. Before pressing the fibers, the fibers were conditioned to 10–12% moisture content by weight. Once the fibers had been sufficiently conditioned, the fibers were placed into a rotating drum with paddle mixers. The fibers were then sprayed using an atomizing air gun with an AW-50 wax emulsion to act as a water retardant, then sprayed with methylene diphenyl diisocyanate (MDI) resin to act as a binder. The wax emulsion was 2% by weight of the fiber mixture and the MDI was 4% by weight of the fiber mixture after spraying and sufficient mixing.

2.2. Board manufacturing

The fiberboards were manufactured using a hot press with a manually controlled hydraulic press system. The platens of the press were heated to a constant temperature of 190 °C to ensure optimal curing of the MDI resin. The fibers for each board formulation that had been previously mixed as described in the Material preparation subsection were placed in an aluminum mold and then the aluminum mold placed in between the heated platens of the press. The platens then compressed the aluminum mold to press the boards; the load applied to the boards was set to 20 metric tons, which is equivalent to 211.1 MPa of applied pressure to the board. This pressure was calculated to yield the desired board density of 620 kg/m^3, with a nominal density range of 558–682 kg/m^3. It should be noted that the hydraulic piston used to apply the pressing load experienced performance issues during the pressing of the blended soybean and wheat boards, with a maximum applied load of only 14 metric tons (equivalent pressure 147.8 MPa) being achieved. The total cycle time from the press closing to opening was approximately 300 s. Three formulations of fiberboard were pressed, including a 100% wheat board, a 100% soybean board, and a 50%/50% soybean/wheat blend board. The edges of the fiberboard were trimmed with a utility knife where necessary to maintain the desired geometry of the fiberboard and remove fibers that were not part of the continuous board.

2.3. Testing methods

Physical and mechanical testing was performed in accordance with ASTM D1037-12 (2012) standard test methods for evaluating properties of wood-based fiber and particle panel materials. The tests conducted for the evaluated formulations include: board density, board thickness, water absorption, thickness swelling, static bending, tension perpendicular to the board surface (internal bond strength), and direct screw withdrawal. Tests were performed using the methods described in ASTM D1037 unless otherwise noted.

2.3.1. Density measurement and thickness measurement methodology

ASTM D1037-12 section 8 specifies that ASTM D2395 method A be followed to obtain the specific gravity of the fiberboard samples. This standard was not followed, however, due to limitations with the cage used in the available testing apparatus; instead a simple density measurement was obtained. Instead an apparent density was measured by first measuring the mass of a sample of fiberboard with a minimum surface area of 9 in^2 in accordance with the standard (50 mm × 50 mm × board thickness samples in this case) then finding the volume through a water displacement measurement using a graduated cylinder. The apparent density was then calculated by using Eq. (1):

$$\rho = \frac{m}{V} \tag{1}$$

where ρ is the apparent density, m is the sample mass, and V is the measured displaced volume. Ten (10) samples were tested

Table 3
Fiberboard moisture content pre-submersion.

Sample formulation	Average moisture content [%]	Standard deviation	Coefficient of variation [%]	Standard error of the mean	Relative error [%]
100% Soybean	6.18	0.00687	11.1	0.00344	5.56
50/50% Soybean/wheat	6.27	0.00691	11.0	0.00346	5.52
100% Wheat	10.0	0.00932	9.30	0.00466	4.65