

## **Final Project Report – Contract No: R-020-029**

### **NDIC Grant Project: Commercial Application of Soybean Stalk as a New Alternative Fiber in Particle Boards**

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Report Date: Feb 11, 2019

The final report summarizes the outcomes of the project titled “Commercial Application of Soybean Stalk as a New Alternative Fiber in Particle Boards”. The research funds for this project were provided by North Dakota Industrial Commission and Masonite PrimeBoard Company located in Wahpeton, ND. The project team included Dr. Dilpreet Bajwa, Dr. Sreekala Bajwa and graduate students from North Dakota State University and Andrew Sunderland and Evan D Sitz from Masonite PrimeBoard Company.

#### **Executive Summary**

In the last decade, significant progress has been made in the utilization of biomass feedstock for producing renewable energy, value added products, as well as a wide range of biochemicals and biomaterials to replace their petroleum analogs. There is an increasing pressure on agricultural biomass utilization for developing sustainable building products. In the upper Midwest region increased demand for wheat straw and its decreasing/fluctuating acreage has doubled the price over the last six years. Masonite PrimeBoard, Inc., a ND based company is a major manufacturer of wheat straw based particleboards. In 2014, NDIC funded a collaborative project between NDSU and PrimeBoard to explore the possibility of using soy stalk as alternate raw material. The first objective of work was to understand the logistics and cost of soy stalk collection, transportation to processing plant. It was found standard square bale sizes measuring 4’x4’, 4’x8’ or 3’x4’ bales weighing under 1000 lbs were ideal for processing. The freight and transportation cost of these bales ranges from 10-15 \$/ton. The ideal material collection and transportation distance was 50-80 miles. The second objective was to understand the factors affecting the efficiency of processing agricultural biomass. The study found that soybean stalk has lower moisture content than wheat straw therefore, it required less drying. However the soybean straw was less bulky (higher bulk density) and much stronger than wheat straw, that requires additional processing time. Additional processing results in the production of more fines, which is a negative, attribute. Third objective investigated the processing equipment changes required to process soybean straw. The data analysis showed that the four main factors (material type, screen size, moisture content and hammer tip speed) had a significant effect on the fines content. The wheat straw’s fines content and viable fraction were both significantly affected by the moisture content, the screen’s hole sizes, and hammer tip speeds. A new hammermiller

design with modified rods, hammers, and lock collars was tested that showed some reduction in the fines and energy consumption. The fourth objective focused on the physico-mechanical properties of the particleboards. The results showed that particleboards made from soybean and wheat straw blends exhibited mechanical properties comparable to 100% wheat straw boards. Wheat straw can be replaced up to 75% without significant reduction in the properties of the boards. Overall, the study demonstrated that soybean stalk could be a viable alternative biomass material that can be tapped for manufacturing particleboards. Use of soybean stalk can help Masonite PrimeBoard to offset some raw material cost and can generate some additional income for soybean farmers. The outcomes of this project would significantly benefit both public and private sectors.

## **1. Introduction**

The concept of turning biomass into a useable product has long been a goal of value-added agriculture. Many plant fibers such as wheat straw, corn stover, soybean stalk, cotton stalk have all been used in commercial products. There has been a significant progress in the utilization of biomass feedstock for producing renewable energy; value added products, as well as a wide range of biochemicals and biomaterials to replace their petroleum analogs. Low-density fiberboard manufactured by Masonite PrimeBoard Corporation is one such example of sustainable use of agricultural biomass. They utilize 30,000 tons of wheat straw each year to make particleboards that are primarily used in the interior doors. Increased demand for wheat straw, unfavorable weather conditions, and fluctuating acreage has doubled the price of wheat straw and added uncertainty in the availability of good quality wheat straw in the Upper Midwest Region. A study funded by North Dakota Industrial Commission helped NDSU to collaborate with industrial partner Masonite PrimeBoards to investigate other potential raw materials that can be blended with wheat straw to manufacture particleboards. The material selected for this study was soybean stalks as soybean acreage is growing in ND.

## **2. Objectives**

The main goal of this project was to explore and demonstrate the feasibility of using soybean stalks as an alternate material for manufacturing particleboards. The specific objectives for this project were:

1. To understand the logistics of collection, baling, and transferring agricultural biomass (primarily soybean stalk) from the field to commercial processing plant.
2. To understand the factors affecting the efficiency of processing agricultural biomass.

3. Identifying changes in the equipment/machinery required to minimize the amount of fines generated during processing of the material.

4. To optimize the composition of the low density particleboards that uses a blend of soybean stalk and wheat straw to have similar or better physical and mechanical properties than the currently manufactured boards.

### **3. Results**

#### **Objective 1: Logistics of collection, baling, and transferring agricultural biomass (primarily soybean stalk) from the field to commercial processing plant.**

The research team first conducted an in-depth research on the biomass collection and transportation logistics. In the past few years there have been some studies related to corn stover, and wheat straw collection and transportation mostly for biomass for fuel or animal feed applications. Some of the constraints that were set in analyzing the cost structure included consistent supply of wheat straw and soy stalk, profitability for farmer, bioprocessor and all the intermediaries. Removal rates that do not damage the soil over long term was also considered a factor for wheat straw. Removal rates of 2.0-2.5 tonne/acre of wheat straw and 1.0 to 1.5 ton of soy stalk were taken into account. Material harvest and collection time ranged from late summer to early fall.

There are three main steps to the harvesting process: mowing, raking, and baling. The optimal collection and baling method was found to be using private contractors (bailers). The standard bale sizes that can fit the current processing equipment include 4'x4', 4'x8' or 3'x4' bales. The preferred bale type was high-density square bales (11-12/ft<sup>3</sup>) weighing 800 to 1200 lbs. The freight and transportation cost of these bales ranges from 10-15 \$/ton. The ideal material collection and transportation distance was less than 80 miles.

Some of the results showed that fall harvest biomass yields are higher however, cons are that higher moisture content, narrow harvest window and sometime lower harvest equipment availability. Trucking is the dominant transportation mode for the processing plant. Transportation cost for every move less than 62.13 miles was found to be approximately \$17/tonne. For longer travel distances such as those over 100 miles, it is often more cost effective to transport the bales by rail. Majority of biomass bales should be directly transported from farm to the processing plant. On-farm storage is usually cost competitive but carries risk for processing plant. On-farm storage costs 8.33 \$/tonne whereas at plant site it varies with location from 9.00-22.00 \$/tonne. Flatbed trucks are most effective for shipping. Open storage is more economical than covered and the bales can be stacked up to 6 rows in height. The increased margin for farm

producers from wheat straw and soy stover harvest can vary from \$80-120 per acre considering variations in the annual crop yield.

## **Objective 2: To understand the factors affecting the efficiency of processing agricultural biomass**

In this task the primary goal was to identify the impact of processing variables on the particle size and production of fines. Both wheat and soybean straw fibers were milled using a W-6-H Model Hammer Mill (Schutte Buffalo, Buffalo, NY) as shown in Figure 1. Two different screen sizes, three milling speeds and three different fiber moisture levels were considered in this experiment.



Figure 1. Hammer Mill

The processing trials conducted on the production lines using soybean stalk and wheat straw blends showed promising results. The soybean stalk had lower moisture content than wheat straw therefore, it required less drying. However the soybean stalk was less bulky (higher bulk density) and much stronger than wheat straw, requiring additional processing. The processed soybean stalk material exhibited stringy strands. Additional processing has also caused production of more fines which is a negative attribute.

The test results showed that the key variables that are related to production of unwanted fines. The four main factors (material type, screen size, moisture content and hammer tip speed) had a significant effect on the fines content, and the fines content was significantly influenced by several higher order interactions between factors. The wheat straw's fines content and viable fraction were both significantly affected by the moisture content, the screen's hole sizes, and hammer tip speeds. However for the soy stalk viable fraction was significantly affected by the fiber's moisture content, the screen's hole sizes, and hammer tip speeds. Overall, it was found that for the fines content, the hammer tip speed had negligible effect on the fines content, while the screen size and moisture content proved to be significant effects.

### **3. Identifying changes in the equipment/machinery required to minimize the amount of fines generated during processing of the material.**

The results of equipment/machinery and hammer milling of soy stalks and wheat straw at various conditions were evaluated by analyzing the fines content and viable fraction produced after

processing of the fibers using hammermill. The results of several processing conditions with multiple replications show that the lowest fines content fraction observed occurred for several conditions, with the lowest finest content being  $0.30\% \pm 0.04\%$  for soybean at 15% moisture using a 44.9 m/s hammer tip speed and 1" round holes screen. The highest fines content was found to be  $2.63\% \pm 0.61\%$  for wheat at 25% moisture using a 35.9 m/s hammer tip speed and 3/8" round holes screen. The highest viable fraction content was  $32.62\% \pm 2.51\%$  for soybean at 5% moisture using a 44.9 m/s hammer tip speed and 3/8" round holes. The lowest viable fraction was  $4.77\% \pm 1.16\%$  for wheat at 15% moisture using a 26.9 m/s hammer tip speed and 1" round holes. From the data analysis, it was found that all four main factors (material type, screen size, moisture content and hammer tip speed) had a significant effect on the material processing and fines generation.

Overall, for both wheat straw and soy stover, the optimal levels to be used in an industrial application are wholly dependent on the cost of production. Reduction of fines helps to keep retention of fibers high, as the fines are unrecoverable for usage in board production. However, it is also possible that the increase in the viable fraction and subsequently smaller amount of material that needs to be further processed could outweigh the financial loss of the fines.

After identifying some weaknesses in the existing equipment/hammermill a new design hammermill with modified rods, hammers, and lock collars (Pentagon System) was used to process the material (supplied by Jacobs Global, IA) . The pentagon bushing allows the hammer to pivot to the area on the screen with the least resistance, this area is where more of the straw leaves the hammermill and this allows the hammermill to operate at a lower amperage. Another innovative feature of the pentagon was the Holeformance elliptical shaped hole. The modified hammermill and screens system is expected to improve grind quality, hammer life, and amp reduction by utilizing two cutting surfaces, the pivoting bushing, and the 4 rod theory instead of 8 rod configuration in current hammermills. The modified hammermill and screens showed some reduction in the fines and energy consumption not as much as the manufacturer claimed.

#### **4. To optimize the composition of the low-density particleboards that uses a blend of soybean stalk and wheat straw**

Tests were performed to characterize the properties of low density particleboards composed of wheat and soybean stalk fibers as well as soybean based resins. These tests include initial resin characterization for potential resin mixtures, testing of the mechanical properties of particleboards.

Six formulations (0% to 75% soybean straw blended with wheat straw) of fiberboard with four replications of each formulation were pressed using a preheated Carver Hot Press Model 4122 (Wabash, IN). Straw fibers were conditioned to 8-12 wt% moisture, then the fibers were sprayed

with resin such that the boards would be 2-4 wt% resin. The fibers were analyzed for moisture content using an Arizona Instrument LLC Computrac® Max® 4000XL Moisture Analyzer (Chandler, AZ). The water and resin was sprayed using an atomizing spray gun, with the fibers themselves being continually agitated in a cement mixer. After sufficient spraying of the resin, the mixture of resin and fibers were laid into a custom produced aluminum mold that would press 305 mm x 305 mm panels. Once the fibers had been laid out, a second, the top half of the mold with a Teflon sheet between it and the fibers was laid onto the top half using guide pins. The two halves of the mold were then placed into a preheated Carver Hot Press Model 4122 (Figure 2). The fibers were then formed and pressed into mats using 190 °C platen temperature and an equivalent pressing pressure of 2.12 MPa for a five minute cycle with a 40 second initial degassing cycle. After cooling and conditioning the boards were tested for physical and mechanical properties using MTS Universal testing machine (Figure 3). The different jigs used to test the particleboards are shown in Figure 4 a-c. Once the boards were removed from the press and cooled, they were cut into samples and tested in accordance with ASTM D1037.

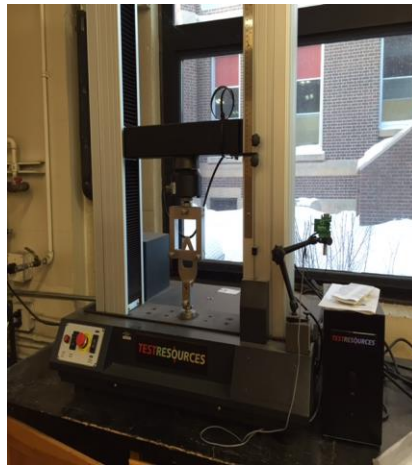


Figure 2. Carver Hot Press

Figure 3. MTS System

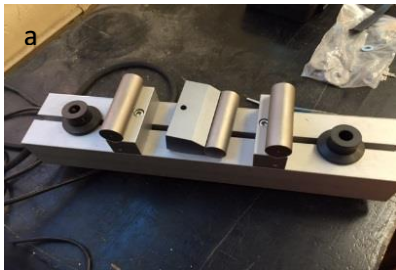


Figure 4. Test jigs a. Three point bending jig b. Bending test c. Internal bond test

## Physical and Mechanical Property Test Results

The results showed that particleboards made from soybean stalks and wheat straw blends exhibited mechanical properties comparable to 100% wheat straw boards. The bulk density test showed that soybean straw fibers are slightly heavier than the wheat straw fibers.

The moisture absorption tests showed that the resin choice and fiber choices were the only significant factors affecting the water absorption. The model accuracy was given by  $R^2 = 86.04\%$ , with adjusted  $R^2 = 83.42\%$ , indicating the model has good adequacy in determining the variability in water absorption properties. The statistical test results for modulus of rupture show that the resin and fiber type and the interaction between the fiber choice and the edge or center sample position were the most influential factors. The model accuracy was given by  $R^2 = 75.06\%$ , with adjusted  $R^2 = 70.57\%$ , indicating the model has moderate accuracy in determining the variability in modulus of rupture properties. The modulus of elasticity test results showed that the resin was the most influential factor, while fiber choice does not have a significant effect. The model accuracy was given by  $R^2 = 52.76\%$ , with adjusted  $R^2 = 48.38\%$ , indicating the model has poor accuracy in determining the variability in modulus of elasticity properties. For internal bond the resin choice and fiber choices as well as their interaction were significant factors in affecting the internal bond strength. For screw withdrawal test resin, fiber type, the sample's position within the board and the interaction between the fiber choice and the resin choice were the most influential factors. It can be concluded that for both wheat and soy stalk, the optimal levels to be used in an industrial application are wholly dependent on the cost of production.

Soy stalk is an effective alternative to wheat straw. For the modulus of rupture, Wheat/Soy 25:75% was the only formulation that had a higher MOR than Wheat 100%. For the modulus of elasticity, three formulations had an average MOE greater than 100% Wheat boards: The test results show that the formulation Wheat /Soy 25:75% had the best overall performance, and would be comparable in performance to Wheat 100% particleboard. For ease of processing soybean, straw can be easily blended up to 75% in wheat straw without significant change in the physico-mechanical properties of particleboards. Although low density wheat and soy straw board don't meet ANSI 208.1 or 208.2 requirements, it is feasible that boards could still be used in low load applications that do not require the standards of ANSI boards.

## 4. Conclusions

The results of this study concluded that soybean stalk fiber has the potential to replace or substitute wheat straw fibers in particleboards. The raw material pricing is influenced by mode of collection and transportation logistics and distance. Square bales weighing 100-1200 lbs are desirable. The optimal distance for procuring material should be less than 80 miles. It was found that soybean stalks are heavier than wheat straw and have less moisture. Processing soybean stalks would require some modifications to existing hammermills designed for wheat straw. The test showed that four main

factors, material types, screen size, moisture content and hammer tip speed are important variables affecting material processing and fines. The mechanical properties of low density particleboards made using soybean stalk up to 75% in wheat straw blend are comparable with 100% wheat straw boards.

### **Acknowledgements**

The funding for this project was provided by the North Dakota Industrial Commission, Project No: Contract No: R-020-029, and Masonite PrimeBoard, Wahpeton, ND. The researchers want to acknowledge the help and support from John Robinson, Andrew Sutherland, and Evan Sitz from Masonite PrimeBoard for collaborating on this project. The principal investigators acknowledge the help from North Dakota State University graduate students, Evan Sitz, Andrew Norris and Chad Rehovsky for conducting the experimentation and data analysis.