ELSEVIER

Industrial Crops and Products 12 (2000) 19–24

INDUSTRIAL CROPS
AND PRODUCTS
AN INTERNATIONAL JOURNAL

www.elsevier.com/locate/indcrop

Physical properties of strawboard as affected by processing parameters

Greggory S. Karr, Enzhi Cheng, Xiuzhi S. Sun *

Kansas State University, Grain Science and Industry Department, Manhattan, KS 66506, USA

Received 8 April 1999; accepted 29 October 1999

Abstract

Wheat straw has been recently considered as an alternative to wood fibers in manufacturing particle boards. The objective of this study was to investigate the effects of processing parameters on straw particle board quality. Commercial ground wheat straw was used in a full factorial experimental design to examine the effects of three processing variables (initial straw moisture content (MC), resin binder content (BC), and press temperature) on strawboard physical and mechanical properties. The MC was tested between 2 and 12%, BC between 2 and 8%, and press temperature between 135 and 218°C. Strawboard density was held constant by controlling the gap in the press mold. Dimensional stability and water resistance was determined by a 24-h water-soak test, and mechanical properties by a three-point flexural test. In the tested parameter range, BC was the most significant factor affecting the strawboard dimensional stability, water resistance and mechanical properties. Initial straw MC was the second most significant factor influencing strawboard quality. MC had a more significant effect on board mechanical properties than on dimensional stability. Press temperature had a more significant effect on the strawboard dimensional stability than on mechanical properties. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Strawboard; Processing variables; Dimensional stability; Mechanical properties

1. Introduction

Agricultural residual straw has been considered as an alternative fiber source to wood fiber for the production of a reconstituted lignocellulosic composite, due to the rising cost and demand of wood fiber (Erwin, 1997). The commercial strawboard industry is relatively new and growing in the United States and Canada. A reconstituted lignocellulosic composite is a pressure-formed product made from one or more fiber substances with a binding agent to hold the components together. Lignocellulosics are naturally occurring polymeric composites whose cell walls are made up primarily of cellulose, hemicellulose, and lignin. The cellulose and hemicellulose are fibrous materials that add strength, and the lignin acts as an adhesive holding the fibers together (Rowell, 1992). A reconstituted product can be made by restraining a mat of lignocellulosic material in a hot press

---

* Corresponding author. Tel.: +1-785-532-4077; fax: +1-785-532-7010.

E-mail address: xss@ksu.edu (X.S. Sun)

0926-6690/00/$ - see front matter © 2000 Elsevier Science B.V. All rights reserved.
PII: S0926-6690(99)00041-2

(Youngquist et al., 1986a). The heat, pressure, and binder 'set' the material in place, but also impart compressive stresses in the product. As the reconstituted product absorbs moisture (reversible and irreversible) swelling occurs. Reversible swelling will occur in two directions: thickness swelling (parallel to compression) and linear expansion (normal to compression). The thickness swelling is a problem in reconstituted products because it involves both reversible and irreversible swelling. Irreversible swelling is caused by the release of compressive stresses that are in the board from the compression process.

Wood fibers and chips have been the traditional sources for lignocellulosic material. Wheat straw has the same basic components as wood, cellulose, lignin, and pentosan, but the percentages of the components are different. Straw contains 29–35% cellulose, 16–21% lignin, and 26–32% pentosan, whereas coniferous wood contains 40–45% cellulose, 26–34% lignin, and 7–14% pentosan (Rowell, 1992). Although, it would be expected that the same processing principles apply to wheat straw, or any other fibrous material, as to wood material in the production of a reconstituted product, little published data are available in this area. Strawboards are now competing with reconstituted wood products, such as particle and fiberboards in markets for floor underlays, furniture, and cabinet construction. The objective of this research was to determine the effects of processing parameters on the physical properties, such as dimensional stability and mechanical properties of strawboard.

Table 1
Low, mid, and high variable levels used in factorial experimental design

Variable	Levels		
	Low	Mid	High
Moisture content (%)	2	7	12
Resin content (%)	2	5	8
Press temperature (°C)	135	177	218

2. Materials and methods

Ground wheat straw was obtained from Natural Fiber Board, Inc. (Minneapolis, KS). The commercial wheat straw had been ground to a particle size ranged from 1.9 to 0.1 cm. The straw was then screened and those between an 8- and a 24-mesh screen were used in this experiment. A diphenylmethane diisocyanate resin binder (Rubinate 1840) was obtained from ICI Polyurethanes (Geismar, LA).

2.1. Experimental design

Based on a preliminary experiment, press times between 1 and 5 min were not important in influencing strawboard quality. In this experiment, three experimental variables in the production of a panel strawboard were investigated: initial straw moisture content (MC), resin binder content (BC), and press temperature. Three levels (low, mid, and high) of each variable were studied. A full factorial design was conducted, MC vs. BC vs. press temperature (3 × 3 × 3 factorial). The values for the low, mid, and high levels are listed in Table 1. Three boards replicates were made for each set of conditions with a total of 81 boards. Each board was then cut into two samples. One sample from each replicate was used for mechanical test, and the other for the water-soak test. The response variables, for this experiment, were dimensional stability (thickness swell, linear expansion and weight gain) and mechanical properties (modulus of rupture (MOR) and modulus of elasticity (MOE)). Board density was measured to determine the standard deviation as a reference. Analysis of variance (ANOVA) was used to analyze the data and the means were compared using the L.S.D. method of the Statistical Analysis System software (SAS, 1992).

2.2. Strawboard preparation

The equilibrium moisture content of the straw at room conditions was about 7 ± 0.5% and was used as the mid level (MC). The high level MC of the straw (12%) was obtained by spraying a calculated amount of distilled water into a plastic bag

Table 2
LSD means and average thickness of samples with varying initial moisture content

Initial MC (%)	Density (g/cm^3)[a]	Thickness (mm)
2	0.635	6.00
7	0.684	5.68
12	0.709	5.60

[a] L.S.D. = 0.007 (g/cm^3).

containing the straw. The bag then was sealed, and the straw shaken to distribute the moisture. The low level MC (2%) was obtained by drying the straw in an oven for 1 h at 100°C. After complete drying, the straw reabsorbed 2% moisture during its transfer into a plastic bag and cooling. In each case, the straw was left sealed for at least 24 h to allow the moisture to equilibrate. The straw was mixed with Rubinate 1840 using a paddle mixer (Hobart Model N50). The resinated straw then was pressed into boards using a 15.2 cm-square aluminum mold and a hot press (Carver Model 3889 Auto C). The aluminum mold was equipped with stops so that a constant gap (0.53 cm) was always achieved. A 5-min press time was used throughout this experiment. A 15.2-cm square strawboard was produced. Each strawboard was then trimmed and cut into two 14 × 4.4-cm boards.

2.3. Board density

The samples used for the water-soak test were preconditioned at 50% RH and 25°C for 1 week prior to the density measurement. The board density of each sample was obtained by measuring the average thickness, width, and length with calipers to calculate a board volume. The bulk density was obtained by dividing the board mass by its volume. The replicate bulk densities were measured then averaged for each experimental point.

2.4. Dimensional stability and water resistance

The samples from the initial board density were soaked in distilled water at room temperature for 24 h. Wet measurements of length, thickness, and weight were recorded immediately after removing the samples from the water. These measurements were used with the initial measurements to calculate thickness swell and linear expansion. The dry and wet weights of each sample were measured to determine the percent weight gain due to the 24-h water-soak. Each point was an average of three 14 × 4.4-cm samples.

2.5. Mechanical properties

ASTM standard method (American Society for Testing and Materials, 1995) was followed for a three-point flex test using an Instron 4466 universal testing machine. The board samples were preconditioned at 25°C and 65% RH for 1 week before testing. The Instron testing machine was used with a crosshead speed of 2.54 mm/min and a 101.6-mm span. The MOR and the MOE were calculated using the equations given in the ASTM (American Society for Testing and Materials, 1995) method. Each point was an average of three 14 × 4.4-cm samples. The ASTM (American Society for Testing and Materials, 1995) method requires a span to sample thickness ratio of 24:1. However, in this experiment an 18:1 ratio was used, which was assumed to test the samples under pure bending (no shear forces) conditions.

3. Results and discussion

3.1. Board density

The average board density of all samples was 0.676 g/cm^3 with a standard deviation of 0.035 g/cm^3. LSD analysis showed that initial straw moisture content was a significant factor to board density. However, the cause of the density variation was ‘springback’, which refers to the increase in thickness of the board as the pressure is released (Youngquist et al., 1986b). Boards with the lower initial MC had a larger initial thickness (Table 2). Because the boards were pressed with a constant gap, this indicates that at a higher MC, the boards had less ‘springback’. The difference in ‘springback’ was less significant between the 7 and

12% MC samples than between the 2 and 7% MC samples. Although the initial straw moisture content did cause some difference in board density, it is believed that the difference is relatively small and will not significantly influence other board properties.

3.2. Dimensional stability and water resistance

The BC was the most significant factor influencing the dimensional stability and water resistance (Table 3). At 8% BC, strawboards had the lowest thickness swell, linear expansion, and weight gain, and at 2% BC, strawboards had the highest of these values. This was expected because the high resin binder content in the strawboard would coat more surface (i.e. lower water absorption). Thus, more bonding sites are available to provide internal strength that can resist the moisture swelling forces (i.e. lower thickness swell and linear expansion).

The initial straw MC between 7 and 12% MC did not affect either the dimensional stability or water resistance (Table 3). However, the thickness-swell was lower at 2% MC than at 7 or 12% MC. This is because that the 2% MC samples had a larger 'springback' than the 7 or 12% MC samples. The 2% MC samples were already preswollen after they were removed from the press (Table 2), which meant that less internal stresses were present in the strawboard. Therefore, the samples with low initial straw MC swelled less in the water-soak test. The samples that had less 'springback' would have higher internal stresses, which would be released in the water-soak test resulting in larger thickness-swell.

Increasing the press temperature from 135 to 177°C showed a slight increase in thickness-swell and decrease in linear expansion and weight gain (Table 3). However, increasing the press temperature from 177 to 218°C decreased the thickness-swell, linear expansion, and water absorption more significantly than from 135 to 177°C. At higher temperatures, the binder would cure more completely, resulting in a higher binder conversion and more crosslinks. This could reduce the moisture absorption and better resist the moisture swelling forces. High temperature might also remove some of the internal stresses in the composite by making the straw become more moldable or plasticizied during the press cycle. A composite made from more plasticized straw

Table 3
Dimensional stability and weight gain means for a 24-h water-soak test[a]

Experimental variable	Thickness swell[b] (%)	Linear expansion (%)	Weight gain (%)
Moisture content (%)			
2	24.8 c	0.28 cd	73.4 c
7	27.9 de	0.29 de	77.6 d
12	27.8 d	0.31 ef	78.6 d
Binder content (%)			
2	41.2 f	0.39 g	112.4 e
5	22.5 b	0.26 bc	65.9 b
8	16.8 a	0.23 a	51.4 a
Press temperature (°C)			
135	27.4 d	0.33 f	78.5 d
177	28.4 e	0.30 de	77.9 d
218	24.7 c	0.25 ab	73.2 c
L.S.D.[c]			
	0.5	0.02	1.9

[a] The reported values represent a mean of nine point values at the same experimental variable level.

[b] Values in the same column followed by different letters are significantly different ($P < 0.05$).

[c] L.S.D. ($P < 0.05$).

Table 4
Mechanical property means for the three experimental variables[a]

Experimental variable	Modulus of rupture[b] (MPa)	Modulus of elasticity (MPa)
Moisture content (%)		
2	19.4 e	2100 e
7	23.3 c	2440 bcd
12	25.3 b	2680 a
Binder content (%)		
2	15.0 f	1910 f
5	24.3 bc	2520 b
8	28.7 a	2780 a
Press temperature (°C)		
135	21.6 d	2330 d
177	22.9 cd	2400 cd
218	23.3 c	2490 bc
L.S.D.[c]		
	1.4	110

[a] The reported values represent a mean of nine point values at the same experimental variable level.

[b] Values in the same column followed by different letters are significantly different ($P<0.05$).

[c] L.S.D. ($P<0.05$).

would retain its shape better after removal from the press.

3.3. Mechanical properties

The BC, similar to dimensional stability, was the most significant factor influencing the MOR and MOE (Table 4). As expected, the MOR and MOE of the strawboards were highest at 8% BC and lowest at 2% BC. Resin binder affects cross-linking sites, so that a high amount will produce a strong and rigid composite.

The initial straw MC was the next most significant factor. The change in mechanical properties from 2 to 12% MC is slightly less than that from 2 to 8% BC (Table 4). This indicates that MC is very important for the mechanical properties of the strawboard. First, water could act as a plasticizer for the straw. When the composite is being pressed, the moisture will make the straw more moldable and with less ‘springback’, and result in higher mechanical properties. Second, water could act as a catalyst in the isocyanate reaction, allowing the binder to react more completely, yielding more crosslinkages (Zucaro and Reen, 1995).

The press temperature was statistically significant, but was the least significant among these three variables (Table 4). No significant difference existed in MOR and MOE between 135 and 177 or 177 and 218°C, but was present between 135 and 218°C. The strawboards had a higher MOR and MOE at higher temperatures. A higher press temperature will provide more heat to the binder causing higher conversion and cross-links, resulting in higher MOR and MOE.

Interactions on board quality among these three variables in the tested range were not significant according to the LSD analysis.

4. Summary

Resin binder content (BC) was the most significant factor that affected the strawboard dimensional stability, water resistance, and mechanical properties. The strawboards were more dimensionally stable and had higher mechanical properties at the higher BC. Strawboards that were pressed with lower initial moisture content (MC) had increased ‘springback’ from the boards pressed with higher MC. While a decrease in MC slightly increased the dimensional stability, it had a greater affect on the mechanical properties. Decreasing the MC, decreased the strawboard mechanical properties. The press temperature had a more significant effect on strawboard dimensional stability than the mechanical properties. As the press temperature increased, the strawboards became more dimensionally stable and water resistant, and only slightly increased the mechanical properties.

References

American Society for Testing and Materials, 1995. Standard Methods of Evaluating the Properties of Wood-Based Fiber and Particle Panel Materials. ASTM, Philadelphia, PA, pp. 137–155 ASTM (D1037-93).

Erwin, L.H., 1997. Strawboard, Biocomposites, and Fields of Dreams. Evergreen. Newsletter for New Uses Council. April.

Rowell, R.M., 1992. Opportunities for lignocellulosic materials and composites. In: ACS Symposium Series, vol. 476. American Chemical Society, Washington, DC, pp. 12–27.

SAS, 1992. SAS User's Guide, Statistics. SAS Institute, Cary NC.

Youngquist, J.A., Krzysik, A., Rowell, R.M., 1986a. Dimensional stability of acetylated aspen flakeboard. Wood Fiber Sci. 18 (1), 90–98.

Youngquist, J.A., Rowell, R.M., Krzysik, A., 1986b. Mechanical properties and dimensional stability of acetylated aspen flakeboard. Holz als Roh-und Werkstoff. 44, 453–457.

Zucaro, J.B., Reen, R.R., 1995. The second forest: filling the wood source gap while creating the environmental board of the 21st century. In: Proceedings of the 29th International Particleboard/Composite Materials Symposium, Washington State University, Pullman, WA.