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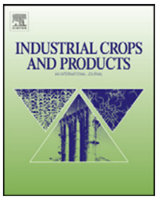

Effect of steam explosion treatment on characteristics of wheat straw

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ABSTRACT

Steam explosion treatments were used to modify straw fiber attributes for panel manufacturing. In particular, the effect of steam temperature and retention time on morphology, acidity, wettability, and ash and silicon contents of wheat straw was studied. After steam explosion treatments, proportion of large particles decreased, while fiber bundles increased. Higher steam temperature and longer retention time resulted in more homogeneous fiber-like material. The results showed that the pH value of the untreated wheat straw fiber was nearly 7 and the pH values and acid buffer capacities of straw were greatly reduced after steam explosion treatments. This indicated that the acidity of straw increased after steam explosion treatments. The dynamic contact angle of the straw before the treatment was nearly 90°, indicating that the straw material without treatment is more hydrophobic. After steam explosion treatments, the contact angle of straw was significantly reduced, showing that the surface wettability of the treated straw was improved. The ash and silicon contents of straw were also significantly reduced by steam explosion treatments. The improved acidity and wettabillity as well as decreased silicon content would contribute to the improved bondability between straw particles and water-soluble adhesive binders.

1. Introduction

In general, crop materials such as straws, sugar cane, and bast fibers (flax and hemp) have lower cellulose and lignin contents, but higher pentosan content than wood (Rowell, 1996). The ash content of all crop materials is significantly higher than that of wood (Youngquist et al., 1993, 1996). More than 90% of the ash in wheat straw was silica (Sauter, 1996). The chemical composition of crop fibers, especially high ash content, has limited the use of these crop materials as raw fiber materials for panel manufacture (Sauter, 1996). In addition, crop materials commonly contain high levels of extractives, which may influence the curing behavior of adhesives (Loxton and Hague, 1996). The pH and acid buffering capacity of aqueous extracts from the non-wood lignocellulosic materials are significantly higher than those of softwood, which increases the gel time of urea-formaldehyde (UF) resin and causes bonding difficulty (Hague et al., 1998). The presence of extractives can also influence the wettability of materials (Young, 1976; Hes and Kuo, 1988). The low wettability is related to the existence of non-polar extractives (Nguyen and Johns, 1979). Generally, there is a waxy layer on the crop material surface (Sauter, 1996; Loxton and Hague, 1996). The water-soluble UF resin is chemically incompatible with the straw material and it is probably the main factor responsible for the reduction of bond quality.

Many attempts have been made to improve the bondability between agricultural materials and adhesives through raw material pretreatment. Wax can usually be extracted by the organic solvents like ethanol/benzene (EB) (Browning, 1967; Thomas, 1959). Han et al. (1999) reported that the wettability of wheat straw surface was improved through EB treatment and the bondability of particleboards made from EB-treated wheat straw was significantly enhanced due to the removal of wax-like substances and other non-polar extractives from the straw surface. High temperature steam treatment has been used to improve dimensional stability of wood products (Giebeler, 1983; Inoue and Norimoto, 1991; Rowell et al., 1998). Lawther et al. (1996) reported that some portion of pectic substances and hemicellulose can be removed from steam-treated wheat straw. Since the pectic substances and high content of hemicellulose in non-wood lignocellulosic materials usually result in poor adhesion between adhesive and these materials, the extraction of these substances would contribute to the improvement of board properties. So far, there are limited studies on the bondability improvement through steam explosion pretreatment.

The overall goal of this work was to investigate the feasibility of improving the bondability between steam explosion pre-treated wheat straw and UF resin. The specific objective was to evaluate the

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Table 1
Summary of sample treatment condition.

Material code	Steam temperature (°C)	Retention time (min)	Pre-soaking in water (°C/h)
Control	–	–	–
20/12 PS[a]	–	–	20/12
190/2	190	2	20/12
190/3	190	3	20/12
200/2	200	2	20/12
200/3	200	3	20/12

[a] PS = pre-soaking.

effects of different treatment conditions (i.e., steam temperature and retention time) on the morphology, acidity, wettability, and chemical properties of wheat straw.

2. Materials and methods

2.1. Raw materials and preparation

Wheat straw was collected from Quebec, Canada. The air-dried wheat straw was hammer-milled and screened to attain furnish with an average length of 25 mm. Subsequently, all the straw material was presoaked in water at 20 °C for 12 h prior to steam explosion treatment.

2.2. Steam explosion treatment

The presoaked wheat straw was treated under various steam explosion conditions shown in Table 1. Steam temperature was 190 °C and 200 °C and the retention time was 2 min and 3 min. The treatment was conducted using a specially designed steam explosion vessel at the pilot plant of the Eastern Laboratory of the FPInnovations—Forintek Division. Each batch of about 850 g of wheat straw was put into the steam chamber. The steam was adjusted to the desired treatment temperature as shown in Table 1. Counting of retention time for each run was started when steam reached to the target temperature. Steam was suddenly released at the end of each treatment to give the explosion effect. The treated straw was collected from the cyclone and pressed to remove the excess water to reach about 60% moisture content (MC).

2.3. Size characterization

The sizes of wheat straw material after various steam explosion treatments were measured in accordance with TAPPI T 233 cm-82 using a Bauer-McNett Fiber Classifier at the FPinnovations—Paprican Division in Vancouver, BC. A sample of 5-g dry straw fiber was used for each treatment condition. The sample was put into a 2000-ml cylinder with boiled water and stirred until all the straw elements were completely separated. The mixture was then diluted to 4000 ml. The sieves with different openings of 10, 12, 14, 28, and 48 meshes were set in five tanks of the classifier in order. Before running the classifier, the tanks were filled with water and the water flow rate was adjusted to 11.3 ± 0.2 l/min. A filter cloth was attached on each of the sample cups and placed securely on the drainpipe of each tank. The diluted test specimen was poured into the first tank and screened into different fractions while going through the sieves in different tanks. The classifier was running exactly 20 min, and then the water was turned off. When the water stopped flowing from the constant level tank, the motor was stopped. The drain plugs from each tank was removed to allow the contents to drain into the sample cups. After the tanks were drained, they were thoroughly washed to remove all fibers from the agitator, tank walls and the screens. The fractions were then accumulated on the tared filter cloths while the water drained through. After draining, the sample cup was removed from the drainpipe of each tank. The fibers were carefully collected from each cloth and dried at 105 °C for 24 h. Weight fractions were calculated based on the total weight of the test sample.

2.4. Evaluation of pH and buffer capacity

The pH, acid and base buffer capacities were evaluated for wheat straw from various steam explosion treatments. A modified test procedure developed from FPInnovations—Forintek Division was used. Straw particles were ground using a small Wiley grinding mill (model 4) and sieved to pass a 40-mesh screen. The sieved straw samples (15 g dried weight) were refluxed in a 200 ml of boiling distilled water for 20 min. The mixture was filtered under vacuum and then diluted to 500 ml. This filtrate solution was used for pH and buffer capacity measurements. A Corning Pinnacle 530 pH meter was calibrated with pH 7.00 and 4.00 standard buffer solutions for acid buffer capacity determination, and with pH 7.00 and 10.00 for base buffer capacity determination. Each filtrate (100 ml) was titrated twice using a 25-ml burette with a standard 0.025N H_2SO_4 solution until reaching pH 3.00 for acid buffering capacity measurement. For base buffer capacity, each filtrate was titrated twice with a standard 0.025N NaOH solution until reaching pH 11. The initial pH was recorded prior to each titration. The buffering capacity, expressed as total milliequivalents (mEq) of acid (or base) per 100 g of oven-dried (OD) sample needed to lower the pH to 3.00 (or 11.00), was calculated as: (1).

$$\text{Buffer capacity (mEq/100 g OD sample)} = \frac{\text{volume of titrant} \times 0.025\text{N of } H_2SO_4 \text{ (or NaOH)} \times 500\,\text{ml} \times 100\,\text{g OD sample}}{\text{volume of titrated sample} \times \text{weight of OD sample used}} \tag{1}$$

Two titration replicates were performed for two samples of each treatment. The initial pH value of each type of straw was the average of eight measurements while the buffer capacity value was the average of four titrations.

2.5. Measurement of wettability

Dynamic contact angles were measured to evaluate the wettability of the straw material treated under various steam explosion conditions. The wettability of water onto the straw samples was determined using the capillary rising height method. The Kruss Laboratory Desktop K12/K14 at Laval University in Quebec City, Canada was used to perform the wetting measurements. Oven-dried sample (0.05 ± 0.005 g) was loaded into the cyclindric glass tube, which was closed at one end with a porous glass sieve. The sample glass tube was then hung on a microbalance and the weight of the samples together with the tube was tarred to zero. The test liquid under the glass tube, maintained at 20 °C, was brought into the sample by penetrating through the glass sieve and wet the sample. The test liquid reservoir rose up to contact with the sample at a rate of 4.5 mm/min. The balance detected the weight increase as a function of time until steady state was reached.

The wetting of hexane on the samples was performed first to obtain the capillary constant. Subsequently, the wetting of water on the samples was performed. Six replications were performed in the measurement of each condition. The contact angle was determined with the modified Washburn equation (2) from the rate of water absorbed onto the samples (slope of the plot of mass^2 versus time as shown in Fig. 4):

$$\cos\theta = \frac{m^2}{t} \times \frac{\eta}{\rho^2 \sigma c} \tag{2}$$