CELLULOSE CHEMISTRY AND TECHNOLOGY

EVALUATION OF THE POTENTIAL OF TOBACCO STALK PULP TO SUBSTITUTE HARDWOOD PULP FOR TOBACCO SHEET PREPARATION

CHAOWEI WU,[*] CHONG LUO,[*] XINSHUN FAN,[*] XIANGFAN WANG[*] and YANGBING WEN[**]

[*]*Henan Cigarette Industry Tobacco Sheet Ltd., Xuchang, Henan, 461100, China*
[**]*Tianjin Key Laboratory of Pulp and Paper, Tianjin University of Science and Technology,*
Tianjin 300457, China
✉ *Corresponding authors: C. Luo, lc19871122@126.com*
Y. Wen, yangbingwen@tust.edu.cn

Tobacco stalk, which has high cellulose and hemicelluloses content, is considered to be a potential raw material for the pulp and paper industry. The objectives of this study have been to evaluate the possibility of producing chemical pulp from tobacco stalk through the soda pulping process, and utilize the tobacco stalk pulp to substitute hardwood pulp during tobacco sheet production. The results showed that high sodium hydroxide (NaOH) loading (about 25% on mass of tobacco stalk) was generally required to produce pulp from tobacco stalk with high strength properties. Moreover, the results of fibre morphology analysis indicated that the diameter of tobacco stalk was similar to that of hardwood pulp. The obtained tobacco stalk pulp can substitute all hardwood pulp, while still maintaining the tensile strength and bulk during the preparation of reconstituted tobacco handsheet. Thus, the production of soda pulp from tobacco stalk to replace hardwood pulp for the preparation of reconstituted tobacco sheet could be a viable option to improve the sustainability of the tobacco industry.

Keywords: tobacco stalk, soda pulping, reconstituted tobacco sheet, tensile strength, bulk

INTRODUCTION

In the past several decades, non-wood fiber crops have received considerable attention from the pulp and paper industry due to the insufficient supply of wood resources in several countries.[1-3] Among the non-wood lignocellulosic materials, wheat straw, rice straw, bamboo, reed and kenaf have been commonly used as raw materials in the pulp and paper industry.[4-7] However, far less research on the utilization of tobacco stalk for the production of pulp has been done, relative to that dedicated to other non-wood materials.

Tobacco is an important commercial crop in the world, especially in Asia. For example, in China alone, more than 450 million tons of tobacco plants are grown annually.[8-10] Since only the leaves of tobacco are used for the production of cigarettes, tobacco stalks are normally treated as solid wastes to be burned as energy or left directly in the field, which not only causes an adverse impact on the subsequent plantation,[8-11] but also creates pollution to the environment. Since tobacco stalk contains comparable contents of cellulose and hemicelluloses to wood and other non-wood species,[12] it has already been utilized for the production of chemical pulps and other cellulose derivatives since the 1960s.[13,14] Soda and soda-AQ pulping processes have been reported to be the two most effective technologies to produce pulp from tobacco stalk for papermaking purposes.[13,15]

In addition, in the tobacco industry, to reduce harmful components and process costs in cigarette manufacturing, the production of reconstituted tobacco sheets through the papermaking process is considered to be a promising option.[16] During the production of reconstituted tobacco sheets, broken tobacco leaf, leaf stalk, fillers, softwood pulp and hardwood pulp are generally utilized,[17-19] among which wood pulps are used to assist the formation and improve the strength of reconstituted tobacco sheets.[20] A challenge for using wood pulps, however, is their high cost, which results in an increase of the cigarette production process costs. Therefore, the substitution of wood pulp with tobacco stalk pulp could be a promising strategy to reduce the cost of producing reconstituted tobacco sheets.

In the work described in this paper, tobacco stalk was processed using the soda pulping process to produce chemical pulp. The obtained pulp was subsequently used for the preparation of reconstituted tobacco sheet to substitute a part of wood pulp. In addition, the physical properties of the reconstituted tobacco sheets were determined to evaluate whether the substitution of wood pulp is feasible for tobacco sheet production. The effects of alkali loading on the chemical and physical properties of the tobacco stalk pulps and reconstituted tobacco sheets were evaluated to select the optimum conditions.

EXPERIMENTAL

Materials

Tobacco stalks, softwood pulp, hardwood pulp, tobacco leaves and tobacco stems were provided by a Chinese tobacco company (Henan Res., China). The obtained tobacco stalks were further processed and thoroughly washed with deionized water to remove impurities, such as root and soil, using a laboratory mixer. After washing, the stalks were air dried for 72 h at room temperature. The moisture content of the air-dried tobacco stalk was approximately 8% (w/w).

Soda pulping

Pulping of the tobacco stalk pulp by the soda pulping process was conducted in a 15 L stainless rotating digester. A series of pulping experiments were conducted with alkali charges of 18-27% w/w (expressed as NaOH). For all the cooking runs, the temperature was raised to 165 °C in 60 min and held at 165 °C for 120 min. The liquid to wood ratio was fixed at 5.0 L/kg. For each pulping experiment, 1000 g oven dry (o.d.) tobacco stalks and the calculated volume of deionized water and sodium hydroxide (NaOH) solution were placed into the digester and mixed for 10 min. Afterwards, the cooking process was performed following the studied conditions. After completion of the cooking run, the tobacco stalk pulp was discharged on a washing screen and thoroughly washed with deionized water until the pH of the filtrate became neutral. Then, the pulp was disintegrated, screened and dewatered to measure the total yield, screened yield and rejects of soda pulping. The screened pulp was stored in polyethylene bags at 4 °C for further utilization.

Preparation of reconstituted tobacco handsheets

The screened tobacco stalk pulp was refined to a freeness of 425 mL using a laboratory refiner (PFI mill). For the preparation of the handsheet, 65 g of refined tobacco leaf and stem pulp, 10 g of softwood pulp, 15 g of precipitated calcium carbonate (PCC), and 10 g of hardwood pulp or tobacco stalk pulp were mixed and disintegrated to a concentration of 0.5% (w/v). Afterwards, 0.15% cationic guar gum (based on the total weight of the pulps) was added into the suspension. After stirring for another 1 min at 700 rpm, the pulp slurry was used to make reconstituted tobacco handsheets, using a standard handmade machine, with a grammage of 60 ± 2 g/m^2, following TAPPI T 205 sp-02.

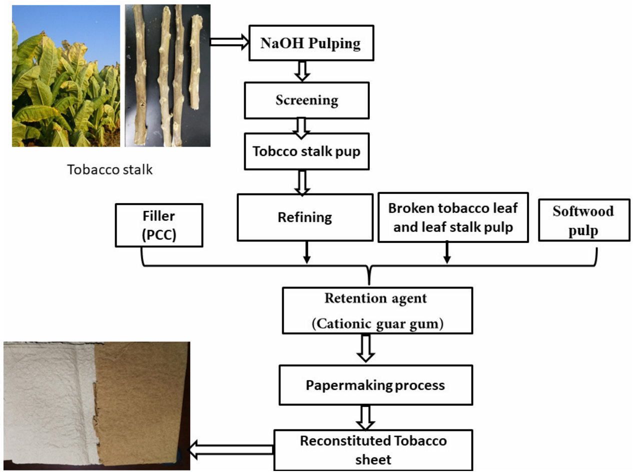

Figure 1: A schematic diagram for pulping and preparation of reconstituted tobacco sheet

Analytical methods

The moisture content of solid samples was measured by drying the sample at 105 ± 2 °C to constant weight. For the chemical composition analysis, the tobacco stalks were cut into smaller pieces of 4-10 cm length and ground by a Willey mill. The fraction that passed through a 60-mesh sieve, yet was retained on an 80-mesh sieve, was collected. Alpha-cellulose was measured according to the procedure described in TAPPI standard method T203 cm-09 by soaking the biomass in 17.5% NaOH solution at 20 °C for 45 min. Klason lignin content was determined following TAPPI T222 om-83. The contents of water and solvent extractives of tobacco stalk samples were determined using a Soxhlet extractor according to TAPPI T 204cm-97.

The freeness of pulp was measured according to TAPPI T227 om-04. The mean fibre length was measured by an L&W Fibre Tester (FT, code 912, Lorentzen & Wettre Co.). The morphology of the pulping fibers was analyzed by optical microscopy (VHX-6000, KEYENCE Co.). A scanning electron microscope (SEM) (SU9000, Hitachi, Japan) was used to observe the morphology of the refined stalk pulp. The handsheets were tested for tensile strength and bulk using TAPPI T 220 sp-01 and TAPPI T411 om-15, respectively.

RESULTS AND DISCUSSION

Chemical composition of tobacco stalk

The contents of cellulose and hemicelluloses in the original tobacco stalk were of 35.8% and 30.5%, respectively, which were similar to other lignocellulosic materials, such as wheat straw and rice straw.[21] The high cellulose and hemicelluloses contents are favorable for using tobacco stalk as a raw material to produce pulp due to the fact that the pulp yield can be maintained at a high level.[22] Similarly to most non-wood raw materials, the ash content of tobacco stalk (8.6% w/w) was remarkably higher than that of the wood species.[23] This might cause some challenges in the pulping process, especially in the chemical recovery process.[24] Compared to most wood species,[25] the lignin content of tobacco stalk was much lower, indicating that delignification during the pulping process could be easier. The content of extractives was comparable to that of other lignocellulosic biomasses.[26] Taken together, these results suggest that tobacco stalk could be an appropriate material for the pulp and paper industry.

Soda pulping and fibre properties

Table 2 shows the effect of alkali loading on the soda pulping of tobacco stalks. As shown in Table 2, with increasing the alkali loading from 18% to 27% (based on the oven-dried mass of tobacco stalks), the total pulp yield decreased from 43.6% to 36.2% and the kappa number decreased from 70.2 to 54.8; this is in agreement with previous studies on soda pulping of other lignocellulosic materials, such as wheat straw and rice straw.[27]

Table 1
Chemical composition of tobacco stalk

Composition	% Oven-dried tobacco
Cellulose	35.8 ± 0.4
Hemicelluloses	30.5 ± 0.4
Lignin	17.2 ± 0.4
Ash	8.6 ± 0.2
Extractives (%)	7.9 ± 0.2

Table 2
Effect of alkali loading on soda pulping of tobacco stalk

NaOH loading (%)	Kappa number	Total yield (%)	Screened yield (%)	Rejects (%)
18	70.2 ± 0.5	43.6 ± 0.4	36.3 ± 0.3	7.3 ± 0.1
22	64.5 ± 0.4	40.9 ± 0.4	34.9 ± 0.3	6.0 ± 0.2
25	58.9 ± 0.3	38.5 ± 0.4	32.9 ± 0.3	5.6 ± 0.3
27	54.8 ± 0.4	36.2 ± 0.3	31.7 ± 0.3	4.6 ± 0.2

The screened pulp yield obtained from soda pulping also decreased with increasing the alkali loading (Table 2). In addition, lower rejects content in the pulp could be obtained with increasing the alkali loading during the pulping process; this could be due to an improvement of the biomass fractionation at high alkali loading.[28] To further evaluate the effect of alkali loading on the pulp properties, the physical properties of the pulp samples were analyzed. The fibre lengths, widths, coarseness and fines content of the tobacco pulp were determined and compared to those of hardwood pulp in Table 3.

Table 3
Fiber properties and fines content of tobacco stalk pulp and hardwood pulp

Sample	Fiber mean length (mm)	Fiber mean width (mm)	Fiber coarseness (mg/m)	Fines content (%)
18% NaOH tobacco pulp	0.85	31.0	0.149	5.71
22% NaOH tobacco pulp	0.81	29.2	0.148	5.61
25% NaOH tobacco pulp	0.80	27.9	0.121	5.55
27% NaOH tobacco pulp	0.78	27.5	0.124	6.10
Hardwood pulp	0.77	28.4	0.118	4.54

Note: hardwood pulp is bleached sulphate pulp

Under the investigated soda pulping conditions, hardwood pulp had the lowest average fibre length, coarseness and fines content. The relatively long fibres in tobacco stalk pulp may result the produced paper with high tensile and tear strength.[12] The increase of fines content in tobacco stalk pulp by increasing the alkali loading could be attributed to the extensive delignification and hydrolysis of carbohydrates at high alkali charge. With respect to fibre average width, no significant difference was observed between tobacco stalk pulp and hardwood pulp (Table 3). These results further demonstrated that tobacco stalk could be used in the pulp and paper industry. To further evaluate the fibre properties, the morphology of tobacco stalk pulp and hardwood pulp fibres was studied (Fig. 2). As shown, under the same magnification, the fibre length and diameter of the tobacco stalk pulp fiber was similar to that of hardwood fiber. Therefore, the tobacco stalk pulp has great potential to substitute hardwood pulp fibers in some products such as reconstituted tobacco sheet.

Properties of produced reconstituted tobacco sheet

Bulk is a critical parameter for reconstituted tobacco sheets.[16,32] The high bulk could adjust the burning speed of cigarettes and promote cigarette combustion, thereby decreasing the generated harmful components, such as carbon oxide and nicotine. Figure 3 shows the effect of the addition of tobacco stalk pulp on the bulk of the reconstituted tobacco sheet. The most important observation was that the tobacco stalk pulp could be used to substitute hardwood pulp during the preparation of the reconstituted tobacco sheet, while maintaining the bulk (Fig. 3). Although the increase of alkali loading during soda pulping resulted in a decrease of the bulk of the reconstituted tobacco sheet, the bulk of the sheet was still very high. Even under the most severe conditions used in this study (27% NaOH loading), the bulk of the reconstituted tobacco sheet was 2.32 cm^3/g, which was only slightly lower than that of the sheet made from hardwood pulp (2.35 cm^3/g). This could be related to the high diameter and coarseness of tobacco stalk pulp.

In addition, in the tobacco industry, reconstituted tobacco sheets are mainly produced by the papermaking process. The addition of wood pulp fibre in the pulp slurry is required not only to reduce smoking harshness, irritation and hazardness,[29,30] but also to improve the strength properties and ensure the normal operation of the papermaking machine.[31] Figure 4 shows the effect of the addition of tobacco stalk pulp on the tensile index of the reconstituted tobacco sheet.

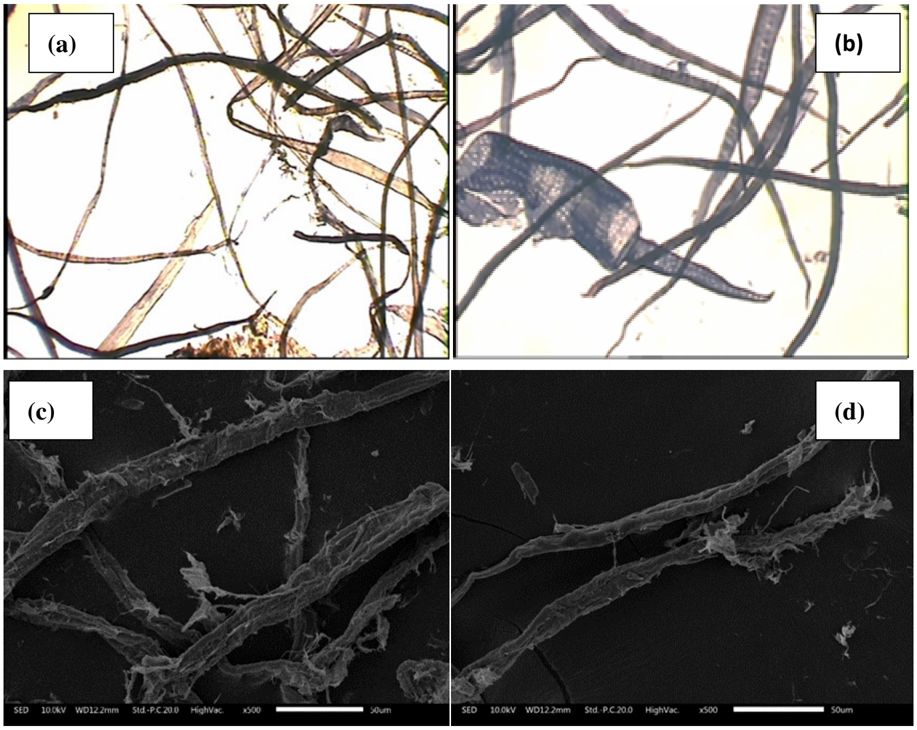

Figure 2: Morphology of tobacco stalk pulp (NaOH loading of 27%) and hardwood pulp: optical microscopy (x100) of tobacco talk pulp (a) and hardwood pulp (b); SEM images of refined tobacco stalk pulp (c) and refined hardwood pulp (d)

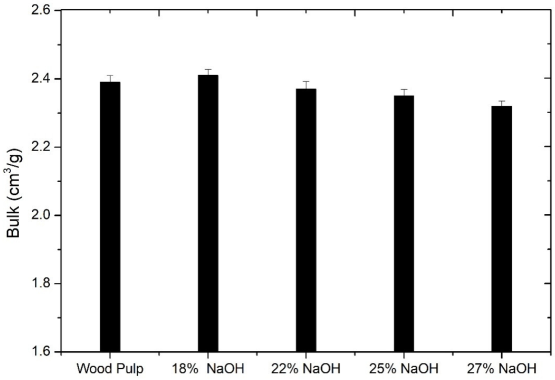

Figure 3: Effect of tobacco stalk pulp addition on the bulk of the reconstituted tobacco sheet

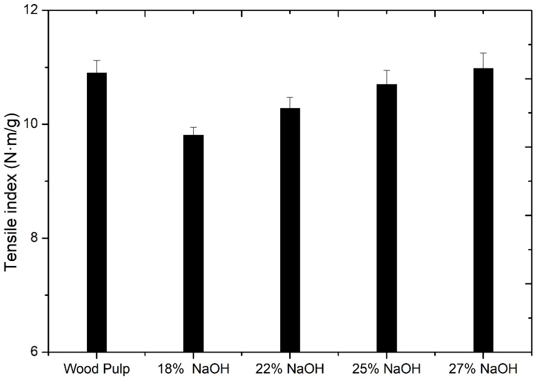

Figure 4: Effect of tobacco stalk pulp addition on tensile index of the reconstituted tobacco sheet

As shown in Figure 4, the tensile index of the reconstituted tobacco sheet increased from 9.81 to 11.1 N·m/g with increasing alkali loading from 18 to 27% (based on o.d. mass of tobacco stalk). This could be due to increased delignification at high alkali loading. With higher removal of lignin at higher alkali loading, more bonding could occur among cellulosic fibres, resulting in an increased tensile strength of the handsheets. For the reconstituted tobacco sheet produced by adding hardwood pulp, the tensile index was 10.9 N·m/g, which was even lower than that of the sheet containing tobacco stalk pulp instead of hardwood pulp (Fig. 4). Overall, these results clearly indicate that the pulp obtained from soda pulping of tobacco stalk could be used as an assist material in the preparation of reconstituted tobacco sheets.

CONCLUSION

Tobacco stalk has high cellulose and hemicelluloses contents and can be considered as a raw material for the pulp and paper industry. The present work has revealed that soda pulping can be a suitable process to process pulp from tobacco stalk. It has been found that the increase of alkali loading during the soda pulping process decreased the pulp yield and kappa number. Also, pulp fibres obtained from soda pulping of tobacco stalk had similar length, diameter and morphological properties to those of hardwood pulp fibres. In conclusion, tobacco stalk pulp can be used to substitute hardwood pulp during the preparation of reconstituted tobacco sheets; the addition of tobacco stalk pulp can maintain or even increase the bulk and tensile index of the obtained reconstituted tobacco sheets.

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