EFFECTS OF BEATING ON TOBACCO STALK MECHANICAL PULP

W. H. GAO, K. F. CHEN, J. ZENG,[*] J. LI, R. D. YANG, F. YANG,
G. H. RAO[*] and H. TAO[*]

State Key Laboratory of Pulp and Paper Engineering, South China University of Technology, Guangzhou, China
[*]*China Tobacco Guangdong Industrial Cooperation, Guangzhou, China*

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Tobacco stalks represent a type of abundant renewable resources. In the present study, tobacco stalks were treated by water at 60 °C for 100 min, to remove water-soluble matters, and then refined at concentrations of 20% (m/m), by refiner mechanical pulping (RMP). To obtain good fiber fibrillation, the pulp was beaten in a PFI mill. The fiber parameters were detected by Kajaani FS-300 and SEM. The analysis revealed that the length of the fibers was similar to that of non-wood material pulp, and also that beating affected fiber morphology. At a PFI mill revolution number of 3500 r (beating degree 33°SR), the physical properties of paper reached the optimum values. The water permeability of the paper recommended it as a hydrophilic material suitable for subsequent papermaking processing. In conclusion, the properties of tobacco stalk pulp recommend it as a papermaking material.

Keywords: tobacco stalk, beating, fiber morphology, SEM analysis, physical properties of paper, water permeability

INTRODUCTION

Nowadays world paper consumption is much higher, paper pulp packaging having become especially attractive.[1] Along the last century, wood species have provided 95% of all raw materials for making cellulose pulp.[2,3] The shortage of conventional raw materials is still one of the serious challenges for pulping, although the worldwide demand for paper products has slightly decreased in recent years. Non-wood plants and agricultural residues attracted renewed interest, especially in countries with insufficient forest resources.[4] Non-wood plants offer several advantages, including short growth cycles, moderate irrigation and fertilization requirements and low lignin content, resulting in reduced energy and chemicals consumption during pulping.[5,6]

Every year, large amounts of tobacco stalks are produced, most of them being disposed of as wastes or fuels, which causes both waste of resources and environmental pollution. In natural tobacco stalks, cellulose and hemicelluloses represent a high percent, approximately 30~40% (m/m), lignin is about 5% (m/m), while water-soluble matters, such as inorganic salts, tannins, pectins, starch, alkaloids, etc., are about 40% (m/m).[7] Plenty of chemicals can be extracted from water-soluble materials. Moreover, paper production requires refined fibers, which have to be mechanically treated for acquiring sufficient bonding. As it is necessary to pretreat the tobacco stalks before refining, which is a highly energy consuming stage, various pretreatments have been investigated to reduce energy consumption and improve paper properties.[8,9] In this research, the goal of pretreatment was to remove water-soluble matters and swell the materials. To obtain internal/external fibrillation of the fibers, after the refiner mechanical treatment, the pulp is usually subjected to beating.[10,11] Fiber surfaces are deliberately enlarged by beating to improve bonding and to develop optimum strength properties.[12] Fiber properties, such as fiber length, width, coarseness, and so on, affect the performance of paper. In the papermaking industry, three components of the non-wood materials are involved: cellulose (40-50% m/m), hemicelluloses (30% m/m) and lignin (15% m/m), while fiber length is of about 1.0-1.5 mm. Non-wood mechanical pulp always consists of short fibers and numerous non-fiber elements. The present study investigates the properties of tobacco stalk mechanical pulp, analyzes fiber morphology and discusses the physical properties of paper. As tobacco stalks may become a papermaking material,[13,14] the study will suggest a new direction in the application of tobacco stalks.

EXPERIMENTAL

Materials and pretreatment

Tobacco stalks, obtained as scraps, from a Chinese plant, were pretreated by water at a solid-to-liquid ratio of 1:7, at 60 °C for 100 min. The aim was mainly to soften tobacco stalks and remove the partially water-soluble matters, which is essential for mechanical pulping. After the pretreatment, the solid and the liquid were separated, and the solid was used for the following step – mechanical pulping.

Mechanical pulping

Pulping was performed in a refiner for mechanical pulping (RMP), a KRK-2500 II high concentration pulp machine, produced by KRK Company in Japan. High consistency refining and a concentration of 20% (m/m) were applied. The process of refining was divided into two steps: in the first step, the gap of the refining disc was of 0.4 mm, in the second, the gap was of 0.2 mm.

Beating

The pulps were diluted by distilled water to attain 10% (m/m) consistency, then refined in a PFI mill, Mark VI NO.621, manufactured by Hamjerb Maskjn A/S Hamar Company, Norway. The speed of the PFI mill was of 620 revolutions per minute and beating was performed at different revolution numbers: 1500, 2500, 3500, 4500, 5500 and 6500 r. Pulps with different beating degrees were obtained. In a subsequent stage, the freeness of the pulp was tested with a Riegler YQ-Z-Grenoble 13 beating degree tester, being determined by fiber fibrillation.

Characterization of tobacco stalk fibers

The refined pulping was stained by He-type dye and its morphology was analyzed by optical microscopy (Olympus BX51). A Kajaani FS-300 analyzer was used for characterizing fiber morphology. Fiber length, width, coarseness and curl index were established. The scanning electron microscope (S3700, Hitachi, Japan) was able to observe the fibers clearly, permitting to analyze both the position and morphology of fibers.

Papermaking

The pulps were dispersed with a standard pulp disintegrator, at 10% consistency (m/m). Handsheets were prepared of a basis weight of 70 g/m^2. The pulps were obtained with PFI mill revolution numbers of 1500, 2500, 3500, 4500, 5500 and 6500 r. The handsheets were equilibrated at constant temperature and humidity for 24 h. According to TAPPI standards testing methods, the physical properties of handsheets, such as tensile index, tear index, bulk, gas permeability and water permeability were tested. In the present study, water permeability was tested with a JC 2000A static drops contact angle/interfacial tension tester and a PDA dynamic permeability analyzer, which show the internal structure of paper. Contact angle (B) is the relation between the material and the liquid, which indicates the wettability of the material. Its values range from 0° to 180°. B = 90° can be taken as the limit of wetting. When B<90°, the material is moistened easily. The lower the B value, the more easily the material is wetted. The contact angle can reflect the ability of paper to resist water penetration, determined by measuring the droplet angle. The droplet will be on the surface of the projection on the screen, while the contact angle will be the phase angle between the tangent and the interface.[15]

The PDA dynamic permeability analyzer accurately and quickly measures the dynamic process of liquid penetration. In the present study, the MAX and T95 values were used to measure the permeability of paper. MAX value, expressing the time when paper is completely wetted by water, reflects the water resistance property of paper. The characteristic T95 value is the time when paper is 95% permeated by the liquid (a 5% water and 95% isopropyl alcohol solution). The value is only affected by the surface structure of the paper. When surface porosity is lower, the time will be longer and paper formation will be better. Also, the T95 value can show the structure of paper surface.

RESULTS AND DISCUSSION

Morphology of RMP pulp

After the pretreatment, the yield of the materials was of 65~67%. In treated materials, the percent of cellulose and hemicelluloses was of about 55~60%, a suitable value for mechanical pulp. Refining of tobacco stalks is a complex process, involving many physical changes that the materials undergo between the two discs. The changes always included: cutting off of fibers, production of numerous tiny fibers, external fibrosis, obtaining of curled fibers, and so on. In the high consistency refining process, friction between fibers plays an important role. Fibrillation was improved and fibers were less cut off. As shown in Figure 1, the fiber ends were stiffer, hardly showing any fiber fibrillation. After the second refining step (Fig. 2), although the fiber width was not reduced, the ends showed increased fiber fibrillation and a higher level of fibrosis.

The numerous chemical components of tobacco stalks are stored in many non-fiber cells. During the refining process, the non-fiber cells were cut off, forming plenty of small debris in pulping. Therefore, numerous cell fragments are visible in the figures.

Characterization of RMP pulp

The application of medium consistency beating mainly depends on the friction among fibers, fiber elastic deformation and mechanical shear function. Fiber friction plays an important role in the process, reducing fiber cutoffs and maintaining fiber length.

As shown in Table 1, when increasing the PFI mill revolution number, the beating degree was enhanced, presenting a trend of linear growth. The beating process produced many tiny fibers and smaller pieces in the pulp, which worsened pulp filtering, so that the beating degree increased.

Table 1
Properties of mechanical pulp

Revolution number (rpm)	Beating degree (^{o}SR)	Fiber length L(w) (mm)	Fiber width W(w) (mm)	Fiber coarseness (mg/m)	Fiber curl (%)
1500	16	1.79	33.65	1.37	14.0
2500	23	1.49	35.41	1.35	14.3
3500	31	1.41	39.66	1.21	14.8
4500	38	1.33	34.90	0.94	13.6
5500	44	1.05	33.24	0.88	12.0
6500	47	0.77	31.96	0.87	8.4

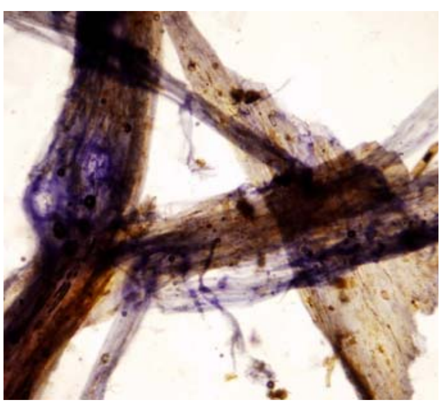

Figure 1: Tobacco stalks RMP (disc gap 0.4 mm, 4×10 times)

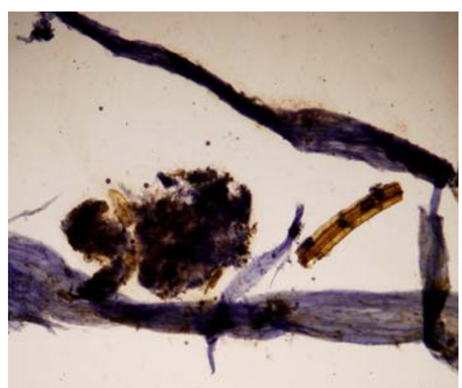

Figure 2: Tobacco stalks RMP (disc gap 0.2 mm, 4×10 times)

The length of the fibers decreased, while their width showed initially an enhancing trend, which was subsequently reduced with the increasing of the PFI mill revolution number (Table 1). The fibers were swelled and beaten into fiber bundles. The length (L (w)) of the fibers was of 1.0-1.8 mm, similar to that of the non-wood material pulp. As non-fiber matters were cut into small fragments or tiny components, the L (w) values decreased. At a PFI mill revolution number of

3500 rpm, fiber width reached a maximum value, while fiber surface presented certain roughness and the fibers became loose. As the revolution number was gradually increased, fibrillation and tiny components occurred on the surface of the loose fibers, leading to average length, lower width. Fiber coarseness (Table 1), referring to the quality of the unit fiber length,[16] depends on the average diameter and perimeter of the fibers. In the pulp, the percent of non-fiber fragments and fiber bundles increased, due to the reduction of the average diameter and perimeter of the fibers and also to the decrease of the coarseness value. Fiber curl index expresses fiber bending in horizontal direction.[16] The curl index of the fibers attained its maximum value at 3500 r. The swollen fibers got fine fibrosis and became softer, which improved fiber bending. When increasing the PFI mill revolution number, the ratio of tiny fibers present in the pulp increased, their deformation was small and thus the curl index decreased.

SEM analysis of fibers

As shown in Figure 3, beating influences considerably the morphology of tobacco stalk fibers. Image a evidences fragments and space gaps among the fibers, while image c shows that fibers were closely woven, showing obvious fibrillation. As may be noted in the pictures, due to the beating process, the pulp produced tiny fibers and fragments. Trivial matters, which played a bridging role, filled in the fibers and improved the density of the randomly woven structure. In conclusion, the beating process affected fiber morphology and improved the structure of the paper.

Effects of beating on paper properties

The main factors affecting the tensile index of paper were the strength of fiber combination and the average fiber length. Beating produced many tiny fibers in the pulp, which could fill in the space gaps among the long fibers, thus increasing the number of hydrogen bonds and improving fiber combination. The tiny fibers played a bridge role in the paper and contributed to its network structure. However, when the beating degree of the pulp continued to increase, the ratio of tiny fibers and small components also increased. Average fiber length was reduced, while the tensile index of the paper decreased (Table 2).

As shown in Table 2, tear index had the same trend as tensile index. The change of tear index should be attributed to the strength and coarseness of the fibers. When the PFI mill revolution number was only 1500 r, the strength of a single fiber was good, while there was hardly any friction among fibers, which resulted in a lower tear index. As the revolution number increased, fiber coarseness was reduced, while their strength, and the combination and friction among fibers enhanced.

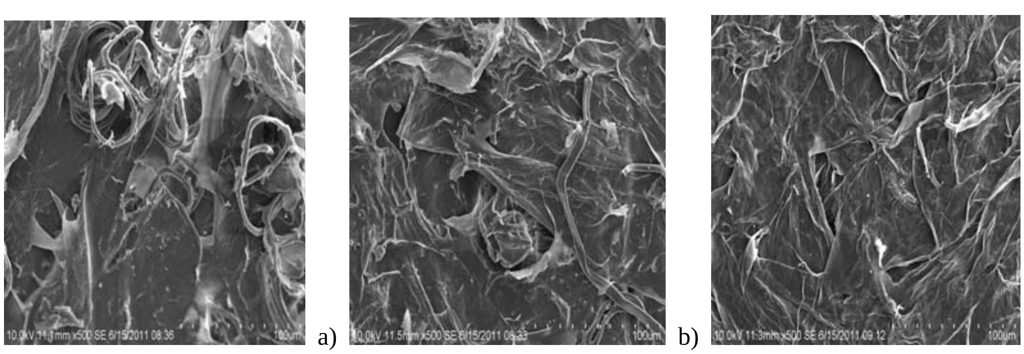

Figure 3: Different beating revolution numbers of RMP: a) 1500 r; b) 3500 r; c) 6500 r

Therefore, the tear index of the paper also increased. However, when fiber coarseness was very low, it decreased single-fiber strength, leading to a decreasing trend in tear index evolution. The burst index (Table 2) of the paper initially showed an increasing trend, with the increase in the PFI mill revolution number, which was followed by its decrease. At a beating revolution number of 3500 r, the fiber showed fine fibrosis and wove best, enhancing the combination among fibers, so that the burst index attained its maximum value. When average fiber length decreased, it became the main factor affecting burst index, causing its reduction.

Table 2
Physical properties of paper

Revolution number (rpm)	Tensile index (N.m/g)	Tear index (mn. m^2/g)	Burst index (kpa. m^2/g)	Specific volume (cm^3/g)	Gas permeability (um.pa/s)
1500	22.81	0.88	0.92	1.83	1.18
2500	28.51	0.98	1.39	1.71	0.86
3500	33.14	1.34	1.63	1.63	0.35
4500	33.03	1.25	1.45	1.53	0.18
5500	32.82	1.16	1.32	1.46	0.09
6500	30.94	1.13	1.24	1.43	0.03

Table 3
Water permeability of paper

Revolution number (rpm)	Contact angle (^{o})	MAX value (s)	T95 value (s)
1500	22.2	0.102	0.201
2500	26.8	0.210	0.505
3500	34.7	0.629	1.801
4500	48.3	0.909	2.425
5500	57.6	0.917	2.664
6500	64.5	1.121	3.486

As the beating degree increased, the specific volume and gas permeability of the paper decreased (Table 2). The values were determined by fiber coarseness, fiber fibrosis and the ratio of tiny fibers present in the paper. When the beating degree increased, the ratio of small non-fiber fragments and tiny fibers enhanced. Trivial matters, which filled in the paper, caused tight fiber weaving, while reducing porosity.

Water permeability of paper

When increasing the PFI mill revolution number, the contact angle showed an increasing trend (Table 3). At a PFI mill revolution number of 1500 r, the fibers hardly showed any fibrillation, and many interspaces occurred in the paper. This allowed liquid penetration and a small contact angle. At a 6500 r value, numerous tightly woven tiny fibers filled in the paper, which hindered the increase of the contact angle through liquid penetration. However, all contact angles were smaller than 90°, which means that all papers were hydrophilic materials. The smallest contact angle, of 22.2^o, could prevent too quick water permeation, unlike the case of tobacco leaves, and was beneficial to the follow-up processing of the paper.

The MAX and T95 values increased with increasing the PFI mill revolution number. The MAX value showed that the maximum water permeability time was of 1.1 s, while the minimum value was of only 0.1 s. The beating process increased the range of the MAX values, which made the material suitable for the following papermaking process, while the T95 value was only affected by the surface porosity of the paper – the lower the paper surface porosity, the higher the T95 value. Fibrillation of swollen fibers improved fiber weaving, making difficult the penetration of water into the paper.

CONCLUSIONS

After pretreatment and refining processes, the tobacco stalks could form mechanical pulp, even though some non-fiber fragments and fiber bundles still remained in the pulp. To obtain good fiber fibrillation, the pulp was beaten in a PFI mill, which improved the pulp properties. When increasing the beating degree, fiber length and coarseness decreased, while the width and curl index first increased, and then decreased. SEM image analysis showed that beating improved the fibrosis of tobacco stalk fibers and produced tiny matters, which filled in the paper. The tensile, tear and burst indices of the paper increased after beating. At a beating revolution number of 3500 r, all properties recorded optimum values, while the specific volume and gas permeability of the paper decreased, as a result of a tight interweaving among the fibers and of the high beating degree. Water permeability indicated that the paper was very suitable for subsequent papermaking processing, such as sizing, coating, and so on. In conclusion, tobacco stalks may become a potential material for papermaking, such as packaging paper, newspaper, case board, and so on, which means a new comprehensive utilization of wastes, while also improving the value of tobacco stalks.

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