Journal of Korea TAPPI
Vol. 31. No. 2, 1999
Printed in Korea

# Analysis of Handsheet Properties of Kenaf Bast and Core Blended Pulps

Myong-Hyeok Pang*, Jong-Moon Park†, and Nam-Seok Cho

## ABSTRACT

This study was to measure the potential of nonwoody fibrous material, kenaf. Whole stalk of kenaf, Hibiscus cannabinus was separated by two parts of bast and core portion, and cooked separately by alkaline method. Morphological characteristic was evaluated using confocal laser scanning microscope (CLSM) and fiber quality analyzer (FQA). The strength properties of handsheets, made by different mixing ratio between kenaf bast and core fibers, were measured.

Cross-sectional area of bast fibers was smaller than that of core fibers, but the bast fibers had a thick cell wall and narrow lumen area. Bast fibers were longer in length than core fibers. Core fibers had thin cell walls, broad lumen areas, and short lengths, and they had collapsed shape even in water. These characteristics of core fibers affected strength properties of handsheet positively. When the amount of core fibers increased, the strength properties of handsheet were increased. When the amount of bast fibers increased, the handsheet had rougher surface and higher air permeability.

## 1. Introduction

Raw materials for papermaking pulps is divided into two categories: wood and nonwoody resource. Although wood is a basic raw material for the paper industry because of availability, the importance of nonwoody cellulosic sources has been increased. With the ever-increasing need of wood for production of paper and paper products and under present environmental situation of devastating the forest, fast-growing sources of raw fibrous material are beneficial.

Fibers have their own peculiar characteristics in anatomical, physical, and chemical properties with many different reason. These properties of fiber affect the properties of paper, when the fibers form a sheet. Among these properties, the morphological characteristic is one of the key factors that greatly affect the properties of finished paper. Kenaf (*Hibiscus cannabinus*) is one of the promising annual plants that give us nonwoody fibrous material with a high productivity.[1-4] Kenaf gives two kinds of fibrous materials, bast and core fibers. This study discusses properties of handsheets prepared by blending of kenaf core and bast fibers and their potentials in papermaking. Fiber quality analyzer (FQA) and confocal laser scanning microscope (CLSM) were used to observe cross-sectional images of fibers in water.

• This research had been supported by Institute of Industrial Technology Policy, Ministry of Commerce, Industry, and Energy, "Development of Alternative Fiber Resources for Korean Traditional Papermaking"(1996).
• School of Forest Resources, Chungbuk National University, Cheongju 361-763, Korea.
* Dept. of Forest Products, Chungbuk National University, Cheongju 361-763, Korea. (Now with Buckman Laboratories (mhpang@buckman.com)).
† Corresponding author: e-mail; jmpark@cbucc.chungbuk.ac.kr

# 2. Materials and Methods

## 2.1 Materials

### 2.1.1 Kenaf

Mature kenaf (*Hibiscus cannabinus* L.) was selected to make handsheet. It was planted and harvested from the experimental farm of Chungbuk National University. After harvest, kenaf was air-dried and stored in ambient condition. Whole stalk of kenaf was fractionated into two parts, bast fibers chip and core fibers chip, then chopped prior to cooking separately.

### 2.1.2 Dispersant and fluorescent dye

Kenaf bast fibers have a tendency to entangle by their long fibers when they were dispersed in water. To avoid this entanglement, polyacrylamide (PAM) was used as dispersant. Acridine Orange (Tetramethyl-3,6-diaminoacrydinium chloride) was used to stain the fibers for CLSM observation.

## 2.2 Methods

### 2.2.1 Preparation of pulps

Bast and core portions were cooked separately. The cooking solution was prepared with sodium hydroxide and distilled water. Active alkali was 20% for both parts, and the liquid to raw material ratios were 8 to 1 for bast and 12 to 1 for core chips. Cooking was performed at 170℃ for 60 minutes. Then, they were thoroughly washed, disintegrated, screened separately using flat screen to remove shieves, dewatered, and stored in refrigerator.

### 2.2.2 Measurement of fiber properties

Fiber lengths were measured by FQA for bast and core fibers after screening. Water retention values (WRV) of two pulps were measured by TAPPI Useful Methods UM-256. Canadian Standard Freeness (CSF) was measured for all kind of mixed pulps.

### 2.2.3 Stock preparation

Table 1 shows the blending ratio at which bast fibers and core fibers were mixed together on the basis of weight. They were stirred to mix well, and PAM solution was added. Before pouring into the British sheet mold, the stock was stirred again enough to give better formation. Fibers for CLSM were lightly dyed with prepared fluorescent dye solution.

**Table 1. Mixing ratios of kenaf bast and core fibers**

| Mixing ratio | Pulp Mixture (%) | |
|---|---|---|
| | Bast fibers | Core fibers |
| B100:C0 | 100 | 0 |
| B75:C25 | 75 | 25 |
| B50:C50 | 50 | 50 |
| B25:C75 | 25 | 75 |
| B0:C100 | 0 | 100 |

### 2.2.4 CLSM observation

A Bio-Rad MRC-1024 CLSM system, attached to a Zeiss Axiophot microscope operated in epifluorescence mode, was used to generate fiber cross-sectional images. Fibers were immersed with water and immersing oil, when the images were generated by CLSM. All observations were made with 63× objective with a numerical aperture of 1.45. The fibers were placed on the glass slide and covered with cover slips. Scan speed was normal, Kalman collection filter was adapted, and the scanning depth along the z-direction was 0.10μm. The Krypton and Argon laser power, iris, gain, and black level values were adjusted to get the best image.[5,6]

#### 2.2.5 Handsheet making

Handsheets for the physical and optical testing were prepared according to the TAPPI Test Methods T205 sp-95 and T402 om-93. Drainage time of every stock in British sheet mold was measured. To get even surface of the handsheet, filter papers soaked in water were placed on both side of the wet web. After pressing, the pressed handsheets were fit into the drying rings. Then, the test sheets were dried under the standard conditions.

#### 2.2.6 Physical properties of handsheets

Calipers, grammages, and apparent densities of handsheets were measured by TAPPI Test Methods T220 sp-96, T410 om-98, and T411 om-97.

#### 2.2.7 Optical properties of handsheets

Brightness and opacity of handsheets were measured by TAPPI Test Methods T519 om-96 and T525 om-92, respectively, and light scattering and absorption coefficients were calculated by T425 om-96.

#### 2.2.8 Mechanical properties of handsheets

TAPPI Test Methods were followed in measuring mechanical properties. The detail methods of each test are; tensile strength by T494 om-96, tear strength by T414 om-98, burst strength by T403 om-97, and MIT folding endurance by T511 om-96. Bekk smoothness of handsheet was measured by T479 om-91, and air resistance of sheet with Gurely method by T460 om-96.

## 3. Results and Discussion

### 3.1 Characteristics of two kenaf pulps

In Table 2, the length characteristics of kenaf fibers are shown. Measured fiber length was ranged from 0.07 to 10.00mm, and the length range from 0.00 to 0.20mm was considered as fines. Bast fibers' length was 1.66mm and it is four times longer than that of core fibers. The longest fibers measured were 5.7mm for bast and 1.4mm for core. Although both fibers had once screened, the fines content from the core fibers reached to almost 30%. Therefore, it is easily expected that a sheet of higher core fraction will show a greater strength properties in tensile and burst.

**Table 2. Fiber lengths of kenaf fibers**

| Fiber | Mean fiber length (mm) | | | Fines content |
|---|---|---|---|---|
| | Arithmetic | Length weighted | Weight weighted | (%) |
| Bast | 1.66 | 2.30 | 2.66 | 12.6 |
| Core | 0.40 | 0.59 | 0.83 | 29.4 |

**Table 3. Dewatering behavior of kenaf pulps**

| Material | Tap water | PAM solution[a] | B100:C0 | B75:C25 | B50:C50 | B25:C75 | B0:C100 |
|---|---|---|---|---|---|---|---|
| Drainage time at sheet mold[b](sec.) | 6 | 6 | 16 | 34 | 50 | 58 | 125 |
| Freeness(CSF, ml) | N/A[c] | N/A | 738 | 725 | 700 | 645 | 568 |

[a] PAM solution was dispersed in tap water, and added to pulp slurry prior to test.
[b] Temperature of the furnish was between 23~24℃ when drainage time was measured.
[c] N/A: not applicable.

### 3.1.1 Dewatering behavior

In Table 3, the variation of freeness by changing mixing ratio of bast and core fibers was shown. Freeness of 100% bast fibers was a little higher than that of 100% core fibers. When the amount of shorter core fibers was increased, the CSF was decreased as shown in Fig. 1 and Table 3. Drainage time of furnishes from B100:C0 to B25:C75 showed steady increase, but the interval between B25:C75 and B0:C100 furnishes lies a burst increase. This result showed that the existence of the shorter fibers or fine fibers had decreased the stock freeness.

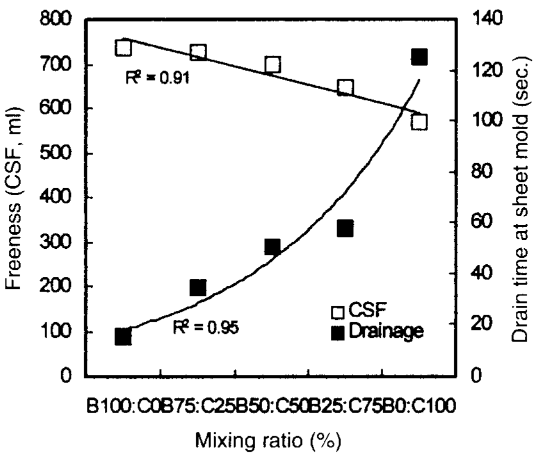


**Fig. 1. Dewatering behavior and mixing ratio of kenaf bast and core fibers.**

### 3.1.2 Water retention values

Fig. 2 illustrates that WRV of short core fibers is almost two times of that of bast fibers as 2.74, whilst WRV of bast fibers is 1.43. This finding shows that kenaf core fibers may have a broader surface area and retain more water than bast fibers. Moreover the big difference in WRVs of the two fibers is attributed to their morphological characteristics. Fig. 3 readily shows that core fibers have a larger lumen and surface area than

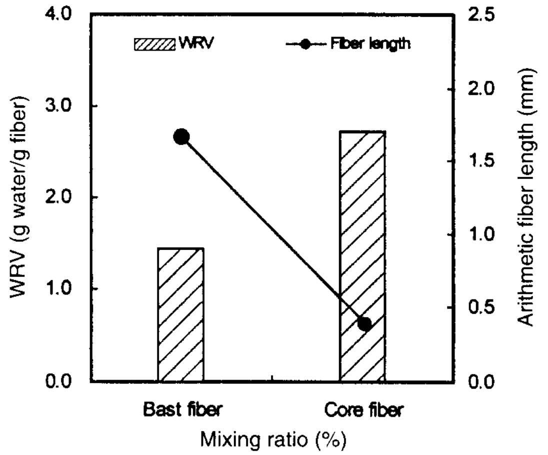


**Fig. 2. Water retention values (WRV) and fiber length of kenaf fibers.**

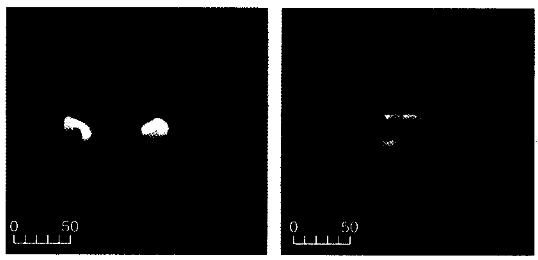


**Fig. 3. CLSM cross-sectional images of kenaf bast (left) and core fibers (right). Scale = μm.**

bast fibers in CLSM images. With these findings, it can be deduced that core fibers retain more water than bast fibers when they are dispersed in water. It is also thought that more water would be retained owing to the larger surface area inside of the core lumen wall comparing to bast fibers, even after centrifuging. Another possible reason of higher WRV of core fibers may be the number of fibers of specific weight basis. Core fibers including parenchyma cells and vessel elements consisted of mono-layer cell. These elements are very easy to collapse, whereas bast fibers do not readily collapse due to their inherent rigidity.

## 3.2 Physical and optical properties of handsheets

Table 4 shows the physical and optical properties of handsheets of blended fibers.

### 3.2.1 Physical properties of handsheets

Fig. 4 shows the apparent density and basis weight of sheets. Basis weight was almost constant by $63 g/m^2$. With the increased addition of core fibers, apparent density of sheet was also increased. As core fibers have thin wall, broad lumen, and short length, they seemed to be easily collapsed. Owing to collapse behavior of core fibers, it might have included increased number of core fibers for the given volume. The sheet having 100% bast fibers (B100:C0) has lower apparent density because the rigid and long bast fibers have larger space in the sheet.

### 3.2.2 Optical properties of handsheets

Brightness of B0:C100 sheet has the lowest value. In Table 4, the variation of opacity from measured sheets was very small. Fig. 5 shows the relationship of scattering and absorption coefficients. Although the variance among the coefficients is not large, the increasing tendency in scattering coefficient is obvious by adding more

**Table 4. Physical and optical properties of kenaf handsheets**

| Properties \ Mixing ratio | B100:C0 | B75:C25 | B50:C50 | B25:C75 | B0: C100 |
|---|---|---|---|---|---|
| Basis weight ($g/m^2$) | 63.1 | 63.0 | 63.0 | 62.8 | 63.0 |
| Caliper (μm) | 170 | 143 | 126 | 109 | 95 |
| Apparent density ($g/cm^3$) | 0.37 | 0.44 | 0.50 | 0.58 | 0.67 |
| Brightness (ISO %) | 27.4 | 27.9 | 27.4 | 26.6 | 24.0 |
| Opacity (%) | 97.5 | 98.4 | 98.4 | 98.6 | 98.5 |
| Light scattering coefficient ($m^2/kg$) | 28.5 | 28.3 | 27.3 | 26.5 | 24.8 |
| Light absorption coefficient ($m^2/kg$) | 14.5 | 13.8 | 13.4 | 13.6 | 14.6 |

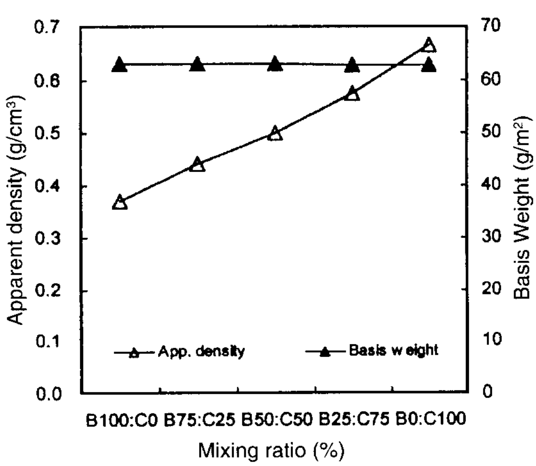


Fig. 4. Apparent density, basis weight and mixing ratio of kenaf bast and core fibers.

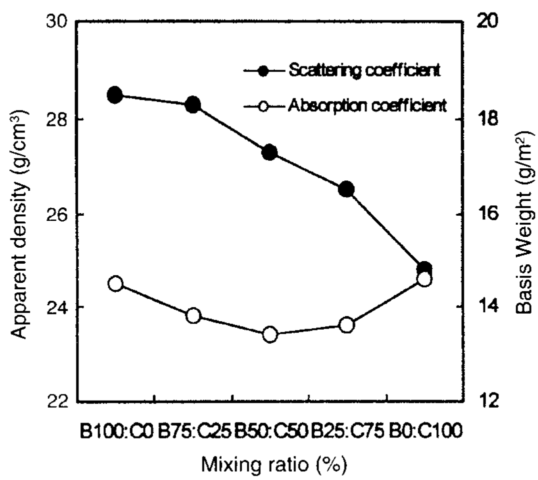


Fig. 5. Scattering coefficient, absorption coefficient and mixing ratio of kenaf bast and core fibers.

**Table 5. Mechanical properties of kenaf handsheets**

| Properties \ Mixing ratio | B100:C0 | B75:C25 | B50:C50 | B25:C75 | B0: C100 |
|---|---|---|---|---|---|
| Apparent density ($g/cm^3$) | 0.37 | 0.44 | 0.50 | 0.58 | 0.67 |
| Burst Index ($kPa \cdot m^2/g$) | 1.79 | 2.10 | 2.71 | 2.88 | 3.08 |
| Tear Index ($mN \cdot m^2/g$) | 96.6 | 91.9 | 73.4 | 51.2 | 25.1 |
| Tensile Index (Nm/g) | 17.9 | 23.6 | 28.2 | 32.3 | 42.3 |
| Breaking Length (km) | 1.83 | 2.40 | 2.88 | 3.30 | 3.86 |
| Zero-span tensile strength (N/cm) | 30.6 | 26.9 | 24.3 | 21.1 | 18.6 |
| $log_{10}$ MIT folding endurance | 0.81 | 1.18 | 1.40 | 1.44 | 1.58 |
| Bekk Smoothness (sec.) | 1 | 2 | 4 | 5 | 5 |
| Air permeability (Gurley sec.) | N/A[a] | 1[b] | 9 | 64 | 300 |

[a] N/A: not applicable.
[b] might be erroneous.

bast fibers into the blended pulps.

### 3.2.3 Mechanical properties of handsheets

The strength properties of kenaf handsheet was given in Table 5. Burst strength of sheet was higher with increasing the amount of core fibers to bast fibers. At the first stage, core fibers in the blended pulps did fill the void volume physically among bast fibers by wet-pressing and drying. Then, they might act as fines fraction or fillers in the sheets.

Tear strength was decreased with the increased amount of short core fibers as the average fiber length of furnish became shorter. None of the fibers was beaten, so fiber length played important role in tear strength. The decreasing trend of tear strength was almost straight. Tensile strength of the sheet made by 100% of long bast fibers resulted in the smallest value, whilst sheet of 100% core fibers gave the highest value. The reason of this phenomena could be explained by fiber bonding. Fibers were not refined, so bast fibers were remained in their intact shape as they were just after cooking. Robinson[7] reported that the fiber bonding is affected by the physical and chemical properties of fibers and the treatments given to the pulp fibers. As the cross-sectional images were seen in Fig. 3, the cross-sectional shape of bast fibers is circular and it has thick cell wall, very small lumen area comparing with core fibers. It is thought that bast fibers might have less fiber-to-fiber bonding than core fibers, owing to their rigidity and lack of internal and external fibrillation.

Zero-span tensile strength of sheet from 100% bast fibers was 30.6N/cm and about 1.6 times higher than that of 100% core fibers. With addition of core fibers to bast fibers, zero-span tensile strength of the sheet has been decreased linearly. Folding endurance of sheets has increasing tendency from B100 to B00 sheets, even though it is not a big difference.

In general, shorter and finer fibers increases smoothness of sheet because they fill the spaces between fibers of sheet surface as shown in Table 5. Sheet made by only bast fibers was too porous to measure by Gurley densometer. The value of 64 Gurley seconds in air permeability test of B25:C75 is similar to that of kraft envelope and 300 Gurley seconds of 100% core sheet is greater than that of index paper[8]. Bekk smoothness values showed little difference. With referring to air permeability test, B0:C100 sheet has the highest value.

## 4. Conclusions

This study was performed to provide a fundamental information on kenaf papermaking and examine the potentials for a new papermaking raw material with separated and blended kenaf bast and core fibers at the same time. The results are summarized as follows:

1. Kenaf bast fibers were characterized by four times longer fiber length than core fibers. However, the lumen width of core fibers was broader than that of bast fibers. It took a longer drainage time for 100% core fibers furnish than other blended fibers, although the freeness had slight difference in the whole range of blending ratio. Long and rigid bast fibers formed a sheet that has a bulky and porous structure.

2. There were a few variations in opacity measurement, but the five kinds of sheets prepared did show high opacity value by 97% over. Owing to the increasing addition of core fibers, there was a descending trend in light scattering coefficient from tested sheets. Low brightness of all kinds of handsheets implies that bleaching may be needed when kenaf sources are pulped in alkaline method for higher grade of paper.

3. Measured strength properties revealed that the sheet made by 100% core fibers was superior to other sheets in all strength properties, except tearing strength, despite of their lowest zero-span tensile strength. Approximately, the strength values of the sheet of 100% core fibers were two times larger than those of 100% bast fibers. Sheet of 100% bast fibers showed three times larger in tearing strength than 100% core fibers.

4. CLSM is proved once again as a good tool for investigation of fiber structure as well. In handling CLSM, careful fiber dyeing technique was required, and the operating technique was also important.

## Literature Cited

1. Nieschlag, H. J., Nelson, G. H., and Wolff, I. A., Tappi 43(3): 193-201 (1960).
2. Nieschlag, H. J., Nelson, G. H., and Wolff, I. A., Tappi 43(12): 993-996 (1960).
3. Nieschlag, H. J., Nelson, G. H., and Wolff, I. A., Tappi 44(5): 319-325 (1961).
4. Kaldor, A. F., Tappi J. 72(9): 137-140 (1989).
5. Jang, H. F., Amiri, R., Seth, R. S., and Karnis, A., Tappi J. 79(4): 203-210 (1996).
6. Jang, H. F., and Seth, R. S., Tappi J., 81(5): 167-173 (1998).
7. Robinson, J. V., Fiber bonding In Pulp and paper: Chemistry and chemical technology, 3rd Ed., Vol. 2., Casey, J. P. Ed., John Willey and Sons, New York, NY, 1980, pp. 915-919.
8. Scott, W. E, Abbott, J. C., and Trosset, S. Eds., Properties of Paper: An Introduction, 2nd Ed., TAPPI PRESS, Atlanta, GA, 1995.
9. Choi, T. H. and Cho, N. S., J. of Korea Tappi 28(4): 7-16 (1996).