Physcial and Fiber Properties of TMP and CTMP from Kenaf Cultivated at Reclaimed Land of Korea

SEUNG-LAK YOON*, YASUO KOJIMA†, DONG-HA CHO†, NAM-HUM KIM†, MIN-JOONG KIM‡, MYOUNG-KU LEE†

*Professor, †Professor, ‡ Graduate Student
Department of Interior Materials Engineering
Jinju National University, KOREA
Corresponding author: mklee@kangwon.ac.kr

ABSTRACT

Fiber characteristics and fiber distribution of thermomechanical pulp(TMP), bisulfite chemithermomechanical pulp(bisulfite CTMP), neutral sulfite chemithermomechanical pulp(neutral sulfite CTMP) from kenaf(*Hibiscus cannabinus* L., Malvaceae) cultivar Tainug-2 cultivated in the reclaimed land of Korea were examined to use effectively nonwood fibers as an alternative raw material sources for papermaking. Yields of TMP and CTMP from kenaf were lower than those of TMP from hardwoods and CTMP from softwoods and hardwoods. Bark fibers of kenaf cultivar Tainung-2 ranged 2.04 to 2.30 mm long and 18.7～19.7㎛ width. Core fibers averaged 0.63 to 0.80 mm long and 29.5～31.4㎛ wide. Coarseness of bark fiber was higher than that of core fiber, and fiber from TMP were higher than those from both bisulfite CTMP and neutral sulfite CTMP. Curl indexes of bark fibers were higher than those of core fibers. However curl indexes were not significantly affected by the pulping conditions. Short fiber distributions were higher in core fibers from TMP and CTMP and long fiber distributions were higher in bark fibers. There was no significant difference in fiber distribution of whole and core fibers obtained from TMP and CTMP. Fibers from neutral sulfite CTMP, however, exhibited a little higher long fiber distribution. Distinct difference in anatomical characteristics was found between core and bast fibers of kenaf plant. Parenchyma cell, pith parenchyma cell and vessel were observed in core fibers and bast fiber in bast sections.

Keywords: Kenaf, TMP, Bisulfite CTMP, Neutral sulfite CTMP, Kenaf fiber, Fiber properties, Coarseness, Fiber distribution

INTRODUCTION

Growth in paper and paperboard consumption in the developed countries continues at the rate of 2-3% annually. Most of main fibrous raw material resources available for papermaking come from wood harvested from the primary forests, resulting in destroying of culturally valuable and ecologically important unnecessarily. Intensive researches of a potential fibrous raw material for papermaking in U.S.A. and other countries suggested kenaf as a promising alternative. Because of currently the strengthened regulations on forest deforestation, the preservation of the fixed carbon source and the reduction policy of CO_2 discharge volume in the world, it becomes a serious problem to supply and demand wood and a raw material for paper production. It is considered that even in Korea a waste resource is recycled actively, and in paper industry a waste paper is reused. However, there are many problems in collecting the waste paper. Therefore, if alternative plant is introduced, which produces much amount of fiber for a short period, the problems of environment and forest conservancy shall be solved in the near future.

To solve the environmental problems, such as the global warming by CO_2 and the forest destruction, kenaf (*Hibiscus cannabinus* L., Malvaceae), an annual plant, has been studied[1,2,3,4,5,6] intensively in these days. Because of growing fast and producing much amount of fiber, kenaf was chosen as the raw material to replace wood in paper industry in USA in 1960s. Kenaf also attracts public attention once again because of the problem of global warming by CO_2. Kenaf grows fast, and so do more photosynthesis, compared to other plants. Therefore, kenaf consumes more CO_2. Kenaf also can be used as the raw material of paper[7,8,9,10], so that wood resource can be saved. For above reasons kenaf is studied widely as a valuable and renewable source in the world.

In Korea different manufacturing methods of Korean traditional paper(Hanji) and their optical properties have been examined[11,12]. Recently study on cultivation of kenaf in Korea and its anatomical characteristics were published by Lee et al. [13].

So in this study, fiber characteristics and fiber distribution of thermomechanical pulp(TMP), bisulfite chemithermomechanical pulp(bisulfite CTMP), neutral sulfite chemithermomechanical pulp(neutral sulfite CTMP) from kenaf cultivar Tainug-2 cultivated at the reclaimed land of Korea were examined to use effectively nonwood fiber as an alternative raw material source for papermaking.

2. MATERIALS AND METHODS

2.1 Materials

Kenaf plants had been cultivated for 152 days with Tainung 2 cultivar at the reclaimed land(126° 40′ 50.70″ E, 35° 47′ 25.90″ N) in 10m by 70m plot of Kyehwa-myon, Buan-gun, Jollabuk-do, Korea. Tainung-2 seeds were provided by James S. Han, USDA Madison, WI. 2~3cm of each chip of core, bast, and whole stalk were prepared in order to investigate the pulping characteristics.

2.2 Preparation of TMP and CTMP

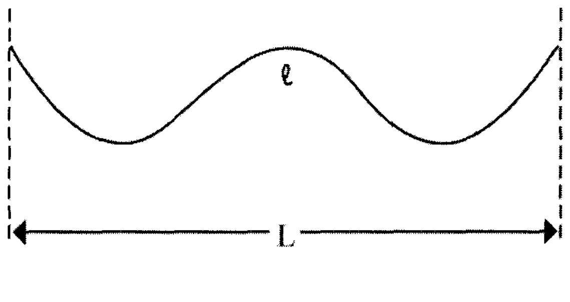
TMP of bast, core and whole fiber sections was prepared using the defibrator. Thermomechanical refining was carried out for 3-min at pre-determined steam pressure with 4-min pre-steaming time. CTMP was also produced from each of the three sections. 5% Na2SO3 and 5% NaHSO3 (oven dry basis) were applied for neutral sulfite and bisulfite CTMP series, respectively.

2.3 Fiber characteristics and distribution

Fiber distribution of each section of pulp refined was measured on a FQA(Fiber Quality Analyzer, OpTest Equipment Inc., Canada) of Fig. 1.

Fig. 1. Fiber Quality Analyzer

Content of fine fiber, length and width of fiber, coarseness, and curl index were measured with FQA. Coarseness of fiber means the weight per unit length expressed as mg/m. Curl index was calculated by the equation of Fig. 2[14].



$$\text{Curl index} = \left(\frac{\ell}{L} - 1\right)$$

Fig. 2. Definition of fiber curl index

2.4 Microscopy analysis of fibers

Each section of core, bast and whole stalks were examined with the optical microscopy.

3. RESULTS AND DISCUSSION

3.1 Pulp yields

Table 1 shows the yield of TMP and CTMP from three different sections- whole, core and bast fibers of kenaf plants.

Table 1. Yields of TMP and CTMP from kenaf three sections

Section	Pulping method	Yield(%)
Whole	TMP	82.6
	Bisulfite CTMP	81.0
	Netural sulfite CTMP	79.1
Core	TMP	87.0
	Bisulfite CTMP	85.2
	Netural sulfite CTMP	84.6
Bark	TMP	77.0
	Bisulfite CTMP	72.2
	Netural sulfite CTMP	72.5

As can be observed, yield of TMP was 87.7% in core fiber, 82.6% in whole stalk and 77.0% in bast fiber. Yield of TMP from kenaf was lower than yield 96.0% of spruce[15]. Yield of bisulfite CTMP from core fiber was 85.2% and neutral sulfite CTMP 84.6%, which were lower than those of TMP. Yields of CTMP from whole stalks were similar to those of core fiber, and yield of bisulfite CTMP was a little higher than that of neutral sulfite CTMP. There was no significant difference in yield of bark fiber between bisulfite CTMP and neutral sulfite CTMP. CTMP yields of three different sections were lower compared to TMP yields. It was found that the yield of CTMP from kenaf also lower than yield 87.3% of spruce and yield 89.0% of birch[15].

3.2 Fiber characteristics of kenaf pulp

FQA was used to examine the fiber characteristics of TMP and CTMP from all three sections in kenaf and the results were shown in Table 2. The highest fine fiber contents were found in the core section of all TMP, bisulfite CTMP, and neutral sulfite CTMP and the lowest content in the bast section.

Table 2. Fiber Characteristics of TMP and CTMP from three parts in kenaf

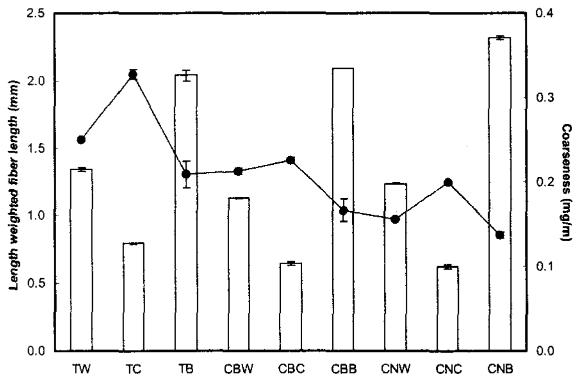
Sample	Fine(%)	Length (mm)	Fiber Width (μm)	Coarseness (mg/m)	Curl Index
TW	5.90	1.34	24.9	0.251	0.083
TC	9.10	0.80	31.4	0.328	0.078
TB	2.49	2.04	19.2	0.209	0.142
CBW	10.45	1.13	25.4	0.213	0.087
CBC	11.84	0.65	29.5	0.226	0.053
CBB	2.54	2.09	19.7	0.167	0.140
CNW	7.60	1.24	25.1	0.156	0.097
CNC	8.98	0.63	31.2	0.200	0.051
CNB	1.06	2.30	18.7	0.138	0.126

***TW**:TMP of whole stalk, **TC**: TMP of core, **TB**: TMP of bast, **CBW**:Bisulfite CTMP of whole stalk, **CBC**: Bisulfite CTMP of core, **CBB**:Bisulfite CTMP of bast, **CNW**:Neutral sulfite of whole stalk CTMP, **CNC**:Neutral sulfite CTMP of core, **CNB**:Neutral sulfite CTMP of bast*

There was a significant difference in lengths of fibers obtained from the bast and core sections of the plants as expected. Bast fibers ranged 2.04 to 2.30 mm in length while core fibers ranged 0.63 to 0.80 mm. As shown in Table 2, core fibers were much wider(29.5～31.4㎛) than bark fibers(18.7～19.7㎛). No significant variation exists in length and width of fibers obtained from different pulping methods and it was found from these results that the fibers were not critically damaged during the pulping processes. The coarseness is defined as mass of fibers per unit length. Fiber thickness, vessel, size of lumen, and fiber gravity contribute to coarseness variation. Core fibers yielded the higher coarseness value than bast fiber. Coarseness values of fibers from TMP were higher than those of fibers from both bisulfite CTMP and neutral sulfite CTMP as well as coarseness value 0.208-0.254mg/m of softwood Jack pine[16], which is a little higher than common softwoods[14]. Fiber curl is defined as deviation from straightness of the fiber axis. Fibers in wood are straight, but they become curled during pulping, mixing and refining. Curl index values of bark fibers were higher than those of core. There was no significant difference in curl index values of fibers obtained from different pulping methods. Curl index values of softwood and hardwood has been reported to be 0.07 and 0.13, respectively[14].

3.3 Relationship between fiber length and coarseness in kenaf

The fiber length and coarseness have an important effect on many properties of paper. Fig. 3 shows the relationship between fiber length and coarseness of TMP and CTMP from three different sections of kenaf.



***TW**:TMP of whole stalk, **TC**: TMP of core, **TB**: TMP of bast, **CBW**:Bisulfite CTMP of whole stalk, **CBC**: Bisulfite CTMP of core, **CBB**:Bisulfite CTMP of bast, **CNW**:Neutral sulfite of whole stalk CTMP, **CNC**:Neutral sulfite CTMP of core, **CNB**:Neutral sulfite CTMP of bast*

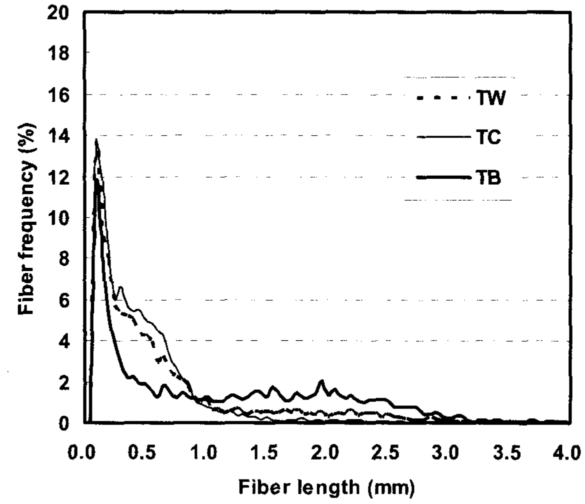
Fig. 3 Relationship between fiber length and coarseness in kenaf

As can be seen, it has a tendency that coarseness decreases as the fiber length increases while coarseness increases as the fiber length decreases. As expected, coarseness value of core fibers was higher than that of bast fibers because core fibers have the short fiber length. The fiber length and coarseness of whole stalks were intermediate values between core and bast fibers.

The fiber length and coarseness of TMP from core fibers was higher than those of CTMP. However, in case of bark fibers, the fiber length of CTMP was a little longer than that of TMP and coarseness of CTMP was a little lower than that of TMP. This tendency can be explained because during pulping processes swelling and elution[17] effects of hemicellulose exceeded the lignin sulfonation.

3.4 Fiber distributions of core, bast and whole parts of kenaf plants

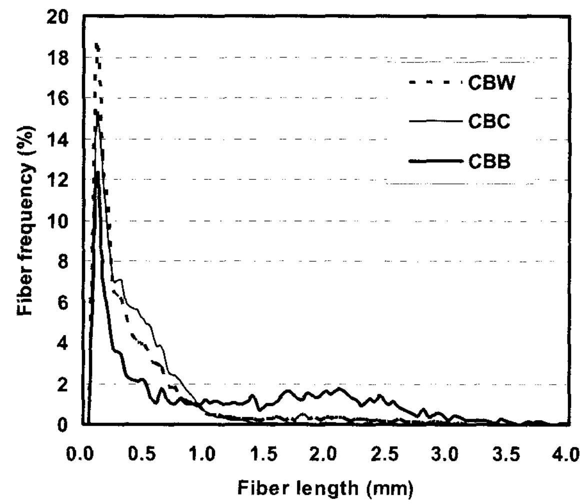
Fiber distributions of TMP and CTMP from core, bast and whole stalks of kenaf plants were measured on a FQA of Fig. 1 and the results were summarized in Fig. 4, 5 and 6. As can be seen in Fig. 4 showing the fiber distributions of TMP obtained from core, bast and whole stalks, there was a significant difference in lengths of fibers obtained from the bask and core sections of the plants. Core fibers composed of higher content of short fiber(about 0.3-1.0mm) and bast fibers contains higher content of long fiber(about 1.0-3.0mm). Fiber distribution of whole stalks showed the intermediate value between core and bast fibers, but it had a tendency to be similar to the value of core fibers.



TW:TMP of whole stalk, TC: TMP of core, TB: TMP of bast

Fig. 4. Fiber distribution of TMP from kenaf three parts

Fig. 5 represents the fiber distribution of bisulfite CTMP form three different parts of kenaf plants. It was hard to find the distinct difference in fiber distribution tendency between bisulfite CTMP and TMP.



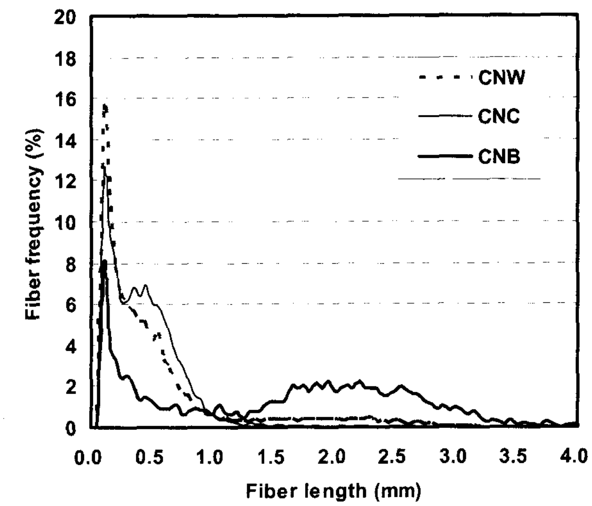
CBW:Bisulfite CTMP of whole stalk, CBC: Bisulfite CTMP of core, CBB:Bisulfite CTMP of bast

Fig 5. Fig. 4. Fiber distribution of bisulfite CTMP from kenaf three parts

Fig. 6 shows the fiber distribution of neutral sulfite CTMP obtained from three different fibers of kenaf plants. Fiber distribution values of neutral sulfite CTMP were similar to those of TMP and bisulfite CTMP contained a little higher long fiber distribution than TMP and bisulfite CTMP.

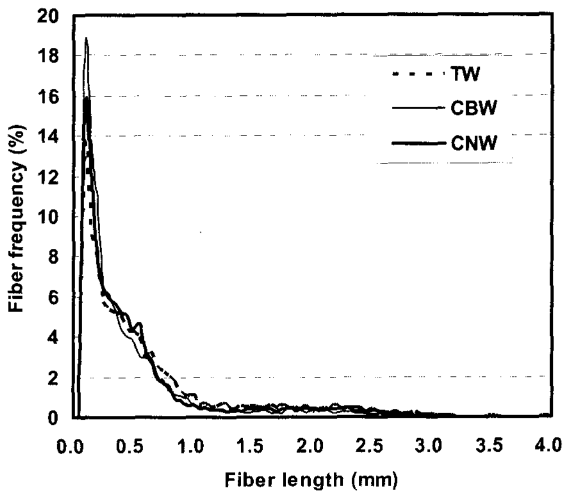
3.5 Fiber distributions of kenaf TMP and CTMP

The results of fiber distribution of kenaf TMP, bisulfite CTMP and neutral sulfite CTMP were summarized in Fig. 7, 8 and 9.



CNW:Neutral sulfite of whole stalk CTMP, CNC:Neutral sulfite CTMP of core, CNB:Neutral sulfite CTMP of bast

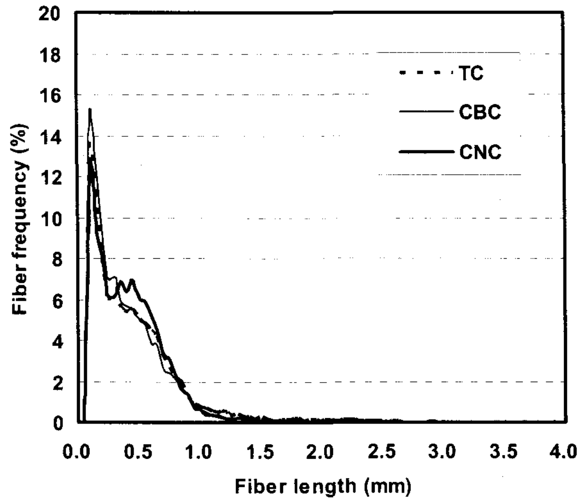
Fig. 6. Fiber distribution of neutral sulfite CTMP from kenaf three parts



TW:TMP of whole stalk, CBW:Bisulfite CTMP of whole stalk, CNW:Neutral sulfite of whole stalk CTMP

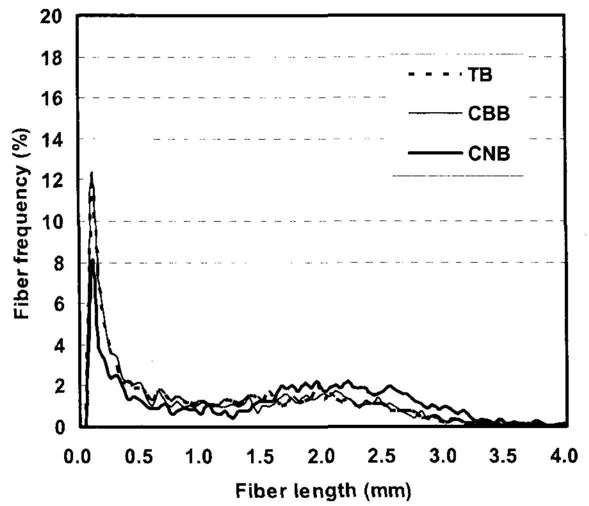
Fig. 7. Fiber distribution of whole stalks from TMP and CTMP

As can be seen in Fig. 7, 8, and 9, fiber distribution of each parts of kenaf plants were not significantly affected by pulping method and showed similar results in all three pulping methods. Core fibers produced by neutral sulfite CTMP were composed of a little more short fibers than those by TMP and bisulfite CTMP, and bast fibers by neutral sulfite CTMP a little more long fibers than those by other two pulping methods. It was found from these results that there was no significant difference in long fiber distributions between TMP and CTMP. Hodgson(18) reported that kenaf TMP consisted of 30% long fiber, kenaf CTMP 41%, and southern pine TMP 55%.



TC: TMP of core, CBC: Bisulfite CTMP of core, CBB:Bisulfite CTMP of bast, CNC:Neutral sulfite CTMP of core,

Fig. 8. Fiber distribution of core fibers from TMP and CTMP



TB: TMP of bast, CBB:Bisulfite CTMP of bast, CNB:Neutral sulfite CTMP of bast

Fig. 9. Fiber distribution of bast fibers from TMP and CTMP

3.6 Anatomical characteristics of kenaf core and bast fibers

Core and bast fibers showed different fiber properties and fiber distribution because of unique cell components. As reported in previous study[13], bast fibers of kenaf plants composed of bast fiber, phloem ray and cortex parenchyma cell, and core fibers contained vessel, wood fiber and ray. Fig. 10 shows the optical micrograph of whole stalks from TMP and CTMP showing the bast fiber with long and thin-walled shape. Fiber length and width measured on a FQA are 2.0-2.3mm and 19μm, respectively. Others are assumed to be the cortex parenchyma cell but vessel is not found in this micrography which is common in bast fibers of kenaf.

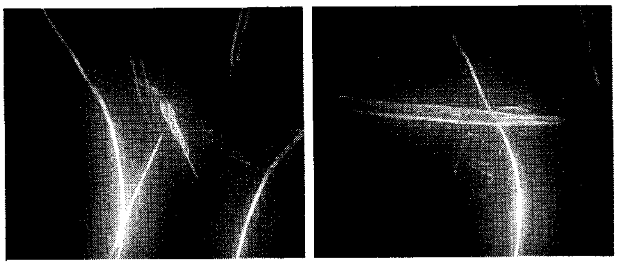


Fig. 10. Optical micrograph of whole stalk from TMP and CTMP showing the bast fiber in bast section

Fig. 11 represents the optical micrograph of core fiber from TMP and CTMP showing the vessel, parenchyma cell and pith parenchyma cell. As can be recognized from Fig. 11 vessel and parenchyma cell had various shapes but cortex parenchyma cell had uniform shape.

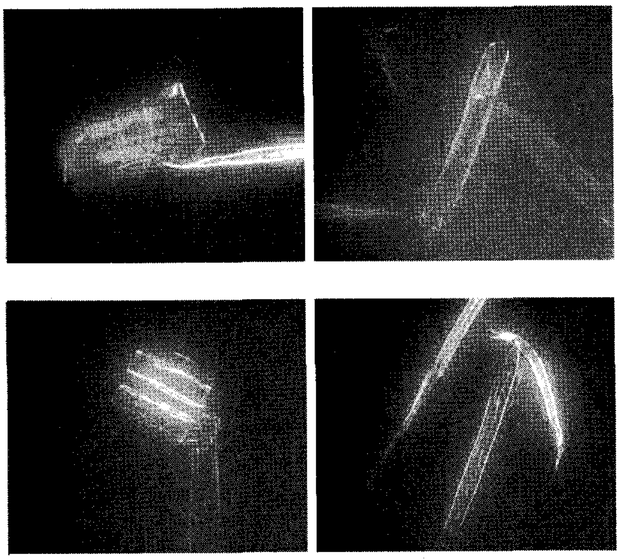


Fig. 11. Optical micrograph of core fiber from TMP and CTMP showing the vessel, parenchyma cell and pith parenchyma cell

Fig. 12 shows the optical micrography of bast fibers from TMP and CTMP showing the bast fiber. Even though

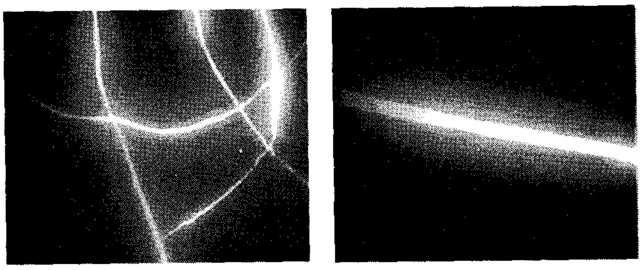


Fig. 12. Optical micrograph of bast section from TMP and CTMP showing the bast fiber

the predominant cell types in bast section of kenaf are bast fiber, phloem ray and cortex parenchyma cell[13], only bast fiber was found. Bast fibers and parenchyma cells serve a role of providing paper with strength. It is generally accepted that paper strength decreases as parenchyma cell content increases and paper strength proportional to the content of bast fiber.

It is expected that strength of paper made only from core fiber of kenaf would be very poor because vessel and parenchyma cell are major cell type in core fibers.

4. Conclusion

Studies on cultivation of kenaf in Korea and its potential use have been carried out since 2001[13], and in this study kenaf Tainung-2 cultivar grown for 152-day at the reclaimed land of Kyehwa-myon, Buan-gun, Jollabuk-do was used to investigate the fiber characteristics and fiber distribution of TMP and CTMP in order to use effectively nonwood fiber as an alternative raw material source for papermaking.

1. Yields of TMP from kenaf were 87.0% in core fibers, 82.6% in whole stalks and 77.0% in bast fibers. These yields were relatively lower than softwood TMP and yields of kenaf CTMP also showed similar results.
2. Fiber length and width of kenaf were 2.04-2.30mm and 18.7-19.7μm in bast fibers and 0.63-0.80mm and 29.5-31.4μm in core fibers, respectively, showing very distinct fiber characteristics between core and bast fibers.
3. Core fibers showed higher coarseness than bast fibers, and fibers from TMP had higher coarseness than other fibers from bisulfite CTMP and neutral sulfite CTMP.
4. Curl index of bast fibers was higher than that of core fibers, and was not significantly affected by pulping method.
5. In terms of fiber distribution, core fibers from TMP and CTMP showed higher distribution of short fiber than bast fibers. Fiber distributions of whole stalks and core fibers from TMP and CTMP had similar tendency but bast fibers from neutral sulfite CTMP showed a little higher values than other fibers from TMP and bisulfite CTMP.
6. There was a significant difference in anatomical characteristics of fibers obtained from the bark and core sections of the plants. The predominant cell types in core fiber were vessel, wood fiber and ray, and bast section bast fiber.

5. Literature cited

1. Bhangoo, M.S., Tehrani, H.S. and Henderson, J., Effect of planting date, nitrogen levels, row spacing, and plan population on kenaf performance in the San Joaquin Valley, Califomia, Agron. J. 78:600-604(1986).
2. Clark, T.F., Cunningham, R.L. and Wolff , I.A., A search for new fiber crops, TAPPI 54(1):63-65(1971).
3. Hovermale, C.H., Effect of row and nitrogen rate on biomass yield of kenaf. p. 35-40. proc. Fourth Int. Kenaf Conf., Int. Kenaf Assoc., Ladonia, TX.(1993).
4. Massey, J.H., Effects of nitrogen levels and row widths on kenaf., Agron.J. 66:822-823.(1974).
5. Nieschlag, H.J., Nelson, G.H., Wolff, I.A. and R.E. Perdue Jr., A search for new fiber crops., TAPPI 43(3):193-201(1960).
6. Sij, J.W. and Turmer, F.T., Varietal evaluations and fertility requirements of kenaf in Southeast Texas., Texas Agr. Expt., Sta. Bul.(1988).
7. P. Khristova, O, Kordsachia., Patt, R., Khider, T, Karrar., Alkakine pulping with additives of kenaf from sudan., Indurstrial Crops and Products 15:229-235(2002).
8. Kuroda, Ken-ichi., Izumi, Akiko., Mazumder, bibhuti B., Yoshito Ohtani, Kanzuhiko Samehima., Characterization of kenaf(Hibiscus cannabinus) lignin by pyrolysis-gas chromatography-mass spectrometry in the presence of tetramethylammonium hydroxide., Journal of Analytical and Applied Pyrolysis. 64:453-463(2002).
9. Khristova p., S. Bentcheva & I. Karar., Soda-AQ Pulp Blends from Kenaf and Sunflower Stalks., Bioresource Technology. 66:99-103(1998).
10. White, G.A. and Higgins, J.J., Growing kenaf for paper. Proc. Second Int. Kenaf conf., Palm Beach, Fl.:27-40(1965).
11. Cho, Nam-seok, and Choi, Tae-Ho., Manufacturing of Korean Traditional Paper(Hanji) from Fast-Growing New Fiber Plant, Kenaf. Journal of Korea TAPPI 28(4):7-16(1996).
12. Tan, Guo-min, and Cho, Nam-seok., Opitical property of Chemimechanical Pulp Sheet from Fast-Growing New Fiber Plant, Kenaf., Journal of Korea TAPPI 29(2):25-35(1997).
13. Lee, Myoung-Ku, and Yoon, Seung-Lak., Utilization of Kenaf Cultivated in Korea(I) -Growth and Anatomical Characteristics of Kenaf Cultivated in Korea., Journal of Korea TAPPI 35(4):68-74(2003).
14. Gordon, Robertson., Olson, James., Allen, Phil., Ben Chan, and Raj Seth., Measurement of fibre length, coarseness, and shape with the fibre quality

analyzer. ,Tappi J. 82(10):93-98(1999).
15. Yoon, Seung-Lak, and Kojima, Yasuoo., The Beating Properties of High Yield Pulp Treated ozone(I) -Fiber length distribution of ozonenation pulp for beating., Mokchae Konghak 25(2):75-80(1997).
16. Kang, Kyu-Young, Zhang, Shu Y. and Shawn D. Mansfield. 2004. The effects of initial spacing on wood density, fibre and pulp properties in jack pine., Holzforschung 58(5):455-463
17. Kojima, Yasuo., Yoon, Seung Lak., Kayama,Tsutomu., Horino, Masashi. and Takeda. Masafumi., A study of production of CTMP from hardwood Part 1.Physical properties of CTMP produced from sulfite-pretreated hardwood chips., Japan TAPPI 63(3):49-60(1988).
18. Hodgson, P. W., Lawford, W. H., Perrault, J. and Thompson, C. A., Commercial paper machine trial of CTMP kenaf in newsprint., Tappi 64(9):161-164(1981).