

PROPERTIES OF KENAF FROM VARIOUS CULTIVARS, GROWTH AND PULPING CONDITIONS

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ABSTRACT

The physical properties of kenaf offer potential as an alternative raw material for the manufacture of paper. Investigations to date have not determined whether core and fiber should be pulped together or separately. Kenaf bast and core fibers of different cultivars were pulped under various kraft pulping conditions and physical properties: density, Canadian Standard freeness, caliper, elongation, tensile strength, tensile index, tensile energy absorption, ISO brightness, printing opacity, bursting strength, burst index, tear resistance, tearing index, and smoothness of the test sheets were measured/analyzed in order to determine the optimum pulping conditions.

INTRODUCTION

“Wood as a paper making raw material is a relative new comer; for nine-tenths of its history, paper was made almost exclusively from nonwood plant fibers” (Atchison and McGovern 1983). Nonwood pulping was at one time a major source of paper. Even today, the combined production of nonwood pulping in India and China alone is greater than that of all wood pulping. Other countries - particularly within Europe - are showing an interest in the development of nonwood pulping.

Kenaf production yields are favorable when compared to wood. An average of 17.8 metric tons (t) per hectare (ha) per annum (a) [8 short tons per acre per year] can be achieved with kenaf fiber versus 2.2 t/ha/a (1 short ton per acre per year) for tree fiber; yet, kenaf pulping in the United States of America (USA) remains

very low (Han et al. 1995). This fact is due to several factors. Kenaf farming is labor intensive compared with tree farming. In addition, kenaf is vulnerable to drought and insect infestation. Raw kenaf is bulky; thus, transportation costs are higher. The price of kenaf is more variable than wood, because kenaf is grown on a seasonal basis. In instances where the fiber must be separated from the core, additional processing is required. Furthermore, kenaf is subject to degradation during storage.

Greater efficiency in the production of kenaf fiber could be achieved through mechanization of farming, pelletization of kenaf to reduce the bulk, and more effective methods of preservation during storage.

Another barrier to the development of a kenaf pulping industry lies in the design of existing pulp mills. Within the USA, pulp mills are designed for wood chips; thus, the pulping of kenaf would necessitate modification (ie., retooling) of the machinery. Retooling is particularly important in order to properly dewater kenaf pulp. Unless there is financial incentive to the use kenaf fiber, it is unlikely that private industry will incur these costs.

One of the advantages of kenaf pulping is its lignin content. Kenaf has a lignin content (bast fiber > 10%, core = 13%) which is much lower than that of softwood (26-32%) or hardwood (20-28%). Furthermore, the lignin content could be reduced by earlier harvesting (Han et al. 1995); thus, reducing pulping energy, chemicals and water pollution.

Commercial kenaf paper has been in circulation worldwide for approximately 15 years. Kenaf pulp has been produced using conventional kraft pulping, soda pulping and bio pulping technologies. Fundamental questions remain, however, concerning whether kenaf bast fiber and core should be pulped together, and what kind of pulping condition should be applied.

The purpose of this experiment is to generate two sets of data: (1) the basic differences between the bast and core fibers when pulped under the same conditions, and (2) criteria for minimal pulping based upon kraft pulping.

KENAF PULPING BACKGROUND

The world's first commercial kenaf pulp mill, Phoenix Pulp & Paper Co., Ltd., is located at Khon Kaen, Thailand. The mill was completed in 1982. Both kenaf bast and core are pulped together, with an annual production capacity of 70,000 t. An analysis of the paper is documented in Leehka and Thapar (1983).

A joint research venture between Voest-Alpine of Austria and C-E Bauer of the USA was conducted in 1982 to develop a high-yield kenaf pulp to blend in newsprint. Both raw chopped kenaf and bleached kenaf kraft pulp were obtained from Phoenix Pulp & Paper Co. Several tests were conducted to determine the best pulp characteristics (Table 23.1).

Chang and Lee (1986) pulped kenaf bast fiber using soda, soda-antraquinone, and alkaline sulfite processes; whereas Voest-Alpine and C-E Bauer pulped both

bast and core together. Therefore, conclusions of the former cannot address advantages or disadvantages in using a combination of both fibers.

Table 23.1. Summary test results of eight pulping trials by Voest-Alpine of Austria and C-E Bauer of USA^a,

	Sample:	A3	A5	A7	A10	A9	A15	A17	A20
Characteristic, unit	Treatment:	TMP	CTMP	CTMP	CTMP	CTMP	CTMP	CTMP	CMP
Chemical applied, %									
H ₂ O ₂		-	2.4	1.0	2.0	3.8	-	-	-
NaOH		-	1.0	1.1	2.7	4.8	1.5	3.5	2.8
Na ₂ SO ₃		-	-	-	-	-	1.3	2.4	2.2
kW·h/ADP Applied		820	552	680	694	753	1041	699	612
Freeness, CSF mL		342	403	403	347	360	196	251	325
Burst Index (kPa·m ² /kg)		0.63	0.54	0.60	0.83	0.83	1.01	1.57	1.04
Tear Index (mN·m ² /kg)		3.7	3.5	3.9	4.6	4.8	4.7	7.7	6.1
Tensile Index (N·m/g)		16	15	17	21	21	24	34	24
Brightness, Elrepho ^b		43.0	50.5	52.5	60.8	60.1	49.6	46.6	39.8
Opacity, %		97.8	93.0	93.5	89.6	89.8	95.0	93.8	96.9
Scattering Coefficient ^c , m ² /kg		48.9	48.0	49.1	51.2	52.0	52.0	44.8	43.7
L-factor ^d , %		35.9	38.9	40.1	42.7	42.0	33.6	39.0	44.8

^a Source: Schoenthaler and Fuentes (1983).

^b Brightness: The standard brightness of paper or pulp is defined as the ratio of the reflectance of an opaque pad of test sheets using light with a wavelength of 457 nm (nanometer or millimicrons) compared to the reflectance of a thick pure white magnesium oxide surface under the same conditions, i.e., R_{00}/R_{∞} at 457 nm. This standard wavelength for measuring brightness is that of a bluish light which was arbitrarily chosen after it was found from tests during 1933-34 that, when observers ranked papers in terms of "brightness," almost invariably the "brighter" of two samples reflected a high percentage of blue light.

^c Scattering coefficient: The scattering coefficient involves measuring the reflectance R_0 of a test sheet backed with a black-velvet-lined cavity, and the reflectance R_{00} when the sheet is backed with enough of the same or similar colored sheets to make the pile opaque.

^d L-Factor: percent of long fiber fraction retained in R14, R28, and R48 screens during Bauer McNett classification of fiber.

MATERIALS AND METHODS

Sample Preparation

Two cultivars of kenaf—Cubano 108 (C - 108) and Tainung 1 —were grown in Madison, Wisconsin in 1993. Physical and chemical properties of the kenaf were published in Han et al. (1995). The cultivar designated “com” is core purchased from Core Products Inc., Charleston, MS. The selected kenaf bast fiber and core were hand separated to 99% purity prior to pulping.

The fibers were placed in 350-mL stainless steel containers. The stainless steel container caps were lined with Garlock gasket to prevent leakage. Each container (containing fiber and cooking liquors) was weighed before and after cooking. Samples which leaked were removed from the experiment.

Pulping

- 1) Preparation of kraft pulping liquor:
 Sodium sulfide (Na_2S): Reagent grade, 99.99+%, $\text{Na}_2\text{S} \cdot 9\text{H}_2\text{O}$, sodium sulfide nonahydrate, was used in place of Na_2S . Converting formula weight (FW) of 240.18 to 78.04 for the extra water molecules.
 Sodium hydroxide (NaOH): pellets, 98.8%
 Water: deionized water was used

Experiment #1	24% Na_2S , 20% NaOH
Experiment #2	22% Na_2S , 18% NaOH
Experiment #3	20% Na_2S , 16% NaOH
Experiment #4	18% Na_2S , 14% NaOH
- 2) Liquid to solid ratio= 7:1 (Chang and Lee 1986):
 The wood chip pulping liquid to solid ratio was approximately 4:1; however, due to the lower density of kenaf fibers this ratio was increased.
- 3) Pulping was conducted in a 350-mL stainless steel air tight container, using a stationary steam digester. Steam was injected into the digester.
- 4) Pulping Temperature = 170°C
 Time = 30 min to 170°C, 30 min at 170°C
- 5) Upon completion of cooking, the samples were cooled to ambient temperature, weighed, and washed with water. The final pulp sample was then made using a British Disintegrator at 50,000 revolutions prior to testing.

Paper Testing

Samples of the handsheets produced from core fiber and bast fiber were tested by the Forest Products Laboratory, Paper Testing Laboratory. A total of 15 tests were conducted.

Any reported values are average values of two to ten individual test results. For example, ISO brightness, printing opacity, and smoothness tests are the average of five tests. Caliper, strain (elongation), tensile strength, tensile index, tensile energy absorption (TEA), bursting strength, burst index, tear strength (resistance), and tearing index values are the average of ten tests. Fiber length by Kajaani procedure is usually an average value of between 4,000 to 7,000 fibers. The Kajaani procedure is an automated method by which the numerical and weighted average fiber length distributions of pulp and paper can be measured (TAPPI, T271 pm-91).

RESULTS AND DISCUSSION

Although four different kraft pulping conditions were described, samples of the fourth pulping condition, 18% of Na_2S and 14% of NaOH , were not tested. At this pulping condition it was difficult to make handsheets; thus, the lowest pulping condition was at 20% Na_2S , 16% NaOH .

Table 23.2 contains the test results of bast fiber handsheets, and Table 23.3 contains the test results of core handsheets under three different pulping conditions. One additional cultivar was introduced in core pulping (com). Table 23.4 is comparison of core fiber and bast fiber in three different pulping conditions.

Table 23.2. Test results of six bast fiber handsheet types (3 pulping conditions per each of the two cultivar types).

	Cultivars:	C-108	C-108	C-108	T-1	T-1	T-1
Property, unit	Na ₂ S/NaOH:	24/20	22/18	20/16	24/20	22/18	20/16
(1) Density, kg/m ³		563.1	597.3	565.8	575.6	560.3	565.8
(2) Freeness, CSF (mL)		633	632	640	607	634	642
(3) Caliper, mm		0.123	0.116	0.121	0.120	0.124	0.123
(4) Strain (elongation), %		2.11	2.44	2.27	2.43	2.20	2.30
(5) Tensile Strength, kN/m		5.63	5.45	5.09	5.58	5.34	5.09
(6) Tensile Index, kN·m/g		0.0822	0.0801	0.0755	0.0825	0.0774	0.0745
(7) TEA, J/m ²		76.13	87.47	75.95	87.69	75.99	75.85
(8) ISO Brightness, %		29.2	24.0	24.4	24.2	25.3	24.7
(9) Printing Opacity, %		96.1	97.4	96.8	97.4	97.2	96.6
(10) Bursting Strength, kPa		330.7	336.4	322.2	367.6	323.4	322.3
(11) Burst Index, kPa·m ² /g		4.86	4.98	4.78	5.43	4.71	4.76
(12) Tear Strength, mN		1466.5	1473.0	1380.2	1475.0	1502.7	1390.2
(13) Tear Index, mN·m ² /g		21.13	21.34	20.32	20.93	21.35	20.42
(14) Smoothness, Sheffield Units		327	322	347	306	330	349
(15) Fiber Length, mm		2.77	2.68	2.87	2.66	2.78	2.86

(7) TEA = tensile energy absorption; (14) Sheffield Units = formerly mL/min.

Table 23.3. Test results of nine core fiber handsheets (three pulping conditions per each of the cultivar types).

Property, unit	Cultivars: C-108 C-108 C-108 T-1 T-1 T-1 Com Com Com									
	Na ₂ S/NaOH:	24/20	22/18	20/16	24/20	22/18	20/16	24/20	22/18	20/16
(1) Density, kg/m ³		948.8	898.6	951.6	897.6	962.3	883.5	879.4	883.4	853.9
(2) Freeness, CSF (mL)		231	213	260	238	229	304	328	315	394
(3) Caliper, mm		0.071	0.076	0.073	0.075	0.070	0.076	0.077	0.076	0.079
(4) Strain (elongation), %		2.38	2.18	2.58	2.33	2.49	2.04	2.45	2.69	2.24
(5) Tensile Strength, kN/m		7.77	6.84	7.92	7.18	7.70	6.58	7.02	7.60	6.39
(6) Tensile Index, kN·m/g		0.1168	0.1014	0.1145	0.1076	0.1151	0.0978	0.1054	0.1139	0.0973
(7) TEA, J/m ²		125.75	101.12	135.85	113.50	129.80	90.52	115.84	138.70	96.02
(8) ISO Brightness, %		22.3	18.9	19.8	18.6	21.0	19.1	23.2	22.4	19.3
(9) Printing Opacity, %		91.4	93.5	93.4	92.6	91.8	95.1	97.3	96.7	97.4
(10) Bursting Strength, kPa		469.5	333.4	435.9	371.7	417.5	312.4	367.4	403.9	324.9
(11) Burst Index, kPa·m ² /g		7.05	4.97	6.31	5.59	6.28	4.61	5.54	6.11	4.93
(12) Tear Strength, mN		367.0	199.2	245.8	219.2	223.4	243.0	356.3	259.3	253.9
(13) Tearing Index, mN·m ² /g		5.5	2.9	3.5	3.3	3.7	3.5	5.1	3.9	3.8
(14) Smoothness, Sheffield unit		69	178	75	94	64	81	38	29	25
(15) Fiber Length, mm		0.80	0.81	0.95	0.75	0.77	0.83	0.71	0.85	0.84

(7) TEA = tensile energy absorption; (14) Sheffield Units = formerly mL/min.

Table 23.4. Test result comparisons of three bast fiber handsheets to three core fiber handsheets in three pulping conditions.

		Bast Fiber Paper			Core Fiber Paper		
Property, unit	Na ₂ S/NaOH:	24/20	22/18	20/16	24/20	22/18	20/16
(1) Density, kg/m ³		569.35	578.8	565.8	908.6	914.8	914.8
(2) Canadian Standard Freeness (mL)		620	633	641	266	252	252
(3) Caliper, mm		0.122	0.120	0.122	0.074	0.074	0.074
(4) Strain (elongation), %		2.27	2.32	2.29	2.39	2.45	2.45
(5) Tensile Strength, kN/m		5.61	5.40	5.09	7.32	7.38	7.38
(6) Tensile Index, kN·m/g		0.0824	0.0788	0.0750	0.1099	0.1101	0.1101
(7) TEA, J/m ²		81.91	81.73	75.90	118.36	123.21	123.21
(8) ISO Brightness, %		26.7	24.7	24.6	21.4	20.8	20.8
(9) Printing Opacity, %		96.8	97.3	96.7	93.8	94.0	94.0
(10) Bursting Strength, kPa		349.2	329.9	322.3	402.9	384.9	384.9
(11) Burst Index, kPa·m ² /g		5.15	4.85	4.77	6.06	5.79	5.79
(12) Tear Resistance, mN		1470.8	1487.9	1385.2	314.2	227.3	227.3
(13) Tearing Index, mN·m ² /g		21.0	21.3	20.4	4.6	3.5	3.5
(14) Smoothness, Sheffield Units		317	326	348	67	90	90
(15) Fiber Length, mm		2.72	2.73	2.87	0.75	0.81	0.81

(7) TEA = tensile energy absorption; (14) Sheffield Units = formerly mL/min.

Table 23.5 contains a direct comparison of core and bast fiber handsheets. All the pulping conditions and cultivars were combined to compare the core fiber paper and bast fiber paper.

Table 23.5. Direct comparison of bast and core fiber handsheets (average of three each).

Test Type	Core Fiber		Comments
	Bast Fiber Paper	Paper	
(1) Density, kg/ m ³	571	906	Fiber << Core
(2) Freeness, CSF (mL)	631	279	Fiber >> Core
(3) Caliper, mm	0.121	0.075	Fiber >> Core
(4) Strain (elongation), %	2.29	2.38	Fiber ≈ Core
(5) Tensile Strength, kN/m	5.36	7.22	Fiber < Core
(6) Tensile Index, kN·m/g	0.0789	0.1078	Fiber << Core
(7) TEA, J/m ² /g	79.86	116.3	Fiber << Core
(8) ISO Brightness, %	25.25	20.5	Fiber > Core
(9) Printing Opacity, %	96.95	94.4	Fiber ≈ Core
(10) Bursting Strength, kPa	333.75	381.8	Fiber < Core
(11) Burst Index, kPa·m ² /g	4.92	5.71	Fiber < Core
(12) Tear Resistance, mN	1446.3	263	Fiber >>> Core
(13) Tearing Index, mN·m ² /g	20.9	3.9	Fiber >>> Core
(14) Smoothness, Sheffield units	329.8	72.6	Fiber >>> Core
(15) Fiber length, Kajaani, mm	2.77	0.812	Fiber >>> Core

(7) TEA = tensile energy absorption; (14) Sheffield Units = formerly mL/min.

In general, the main difference in paper quality between the core fiber and bast fiber is derived from the fact that bast fiber is long and thin, and core fiber is short and thick. There are also chemical differences between core and bast fiber.

A general discussion of the quality of paper could be misleading, due to the fact that a cultivar of grades are used commercially. Discussions will be focused on individual test results.

Density, kg/m³

The density of paper is measured in weight per volume. There was no observable change in densities under various pulping conditions; however, considerable

differences existed between core and bast fiber paper. The core had a maximum density of 906 kg/m³ versus fiber at 570 kg/m³.

Canadian Standard Freeness, CSF (mL)

A low freeness means that the paper machine will have to operate relatively slowly - a condition that is usually undesirable. There was a little observable change in freeness due to the various pulping conditions; however, pulp made from core has considerably lower freeness than the pulp made from bast fiber (Figure 23.1). The average CSF for the core was 279 versus 631 for the bast fiber. The stalk pulps prepared by Voest-Alpine shows test values lower by comparison, from a low of 196 to high of 403 (Table 23.1). This low freeness value is the major drawback for whole-stalk pulping.

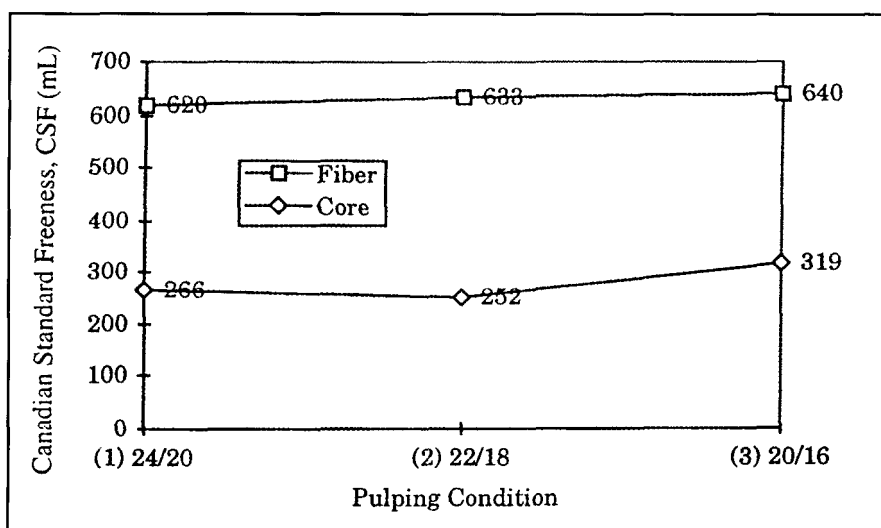


Figure 23.1. Changes in freeness.

Caliper, mm

The nominal thickness of paper is known as its caliper. When using core fiber there is a tendency for the caliper to increase due to a weak pulping condition.

Strain (elongation), %

Defined as the maximum tensile strain before sample failure.

Tensile Strength, kN/m

For each of the three pulping conditions there was a gradual reduction in tensile strength in the paper made from bast fiber, corresponding to a weakening of the pulping condition. There was no observable variation in tensile strength in paper made from core fiber (Figure 23.2).

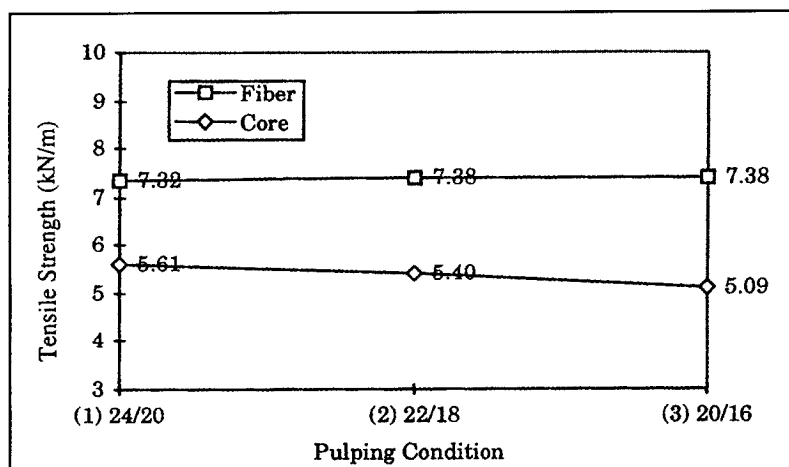


Figure 23.2 Changes in tensile strength.

Tensile Index, kNm/g

Tensile index obtained by dividing the tensile strength by the basis weight, followed the same pattern as the tensile strength.

Tensile Energy Absorption (TEA), J/m²

TEA, another mechanical property, decreased as the pulping condition became weak.

ISO Brightness, %

Decrease in the brightness of the paper was well reflected throughout the three pulping conditions (Figure 23.3).

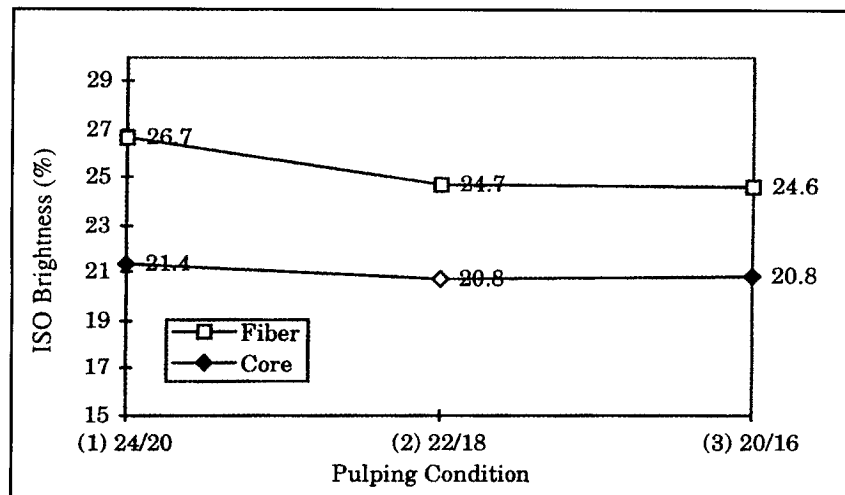


Figure 23.3. Changes in ISO brightness.

Printing Opacity, %

No change,

Bursting Strength, kPa

Decreased as the pulping condition became weak (Figure 23.4).

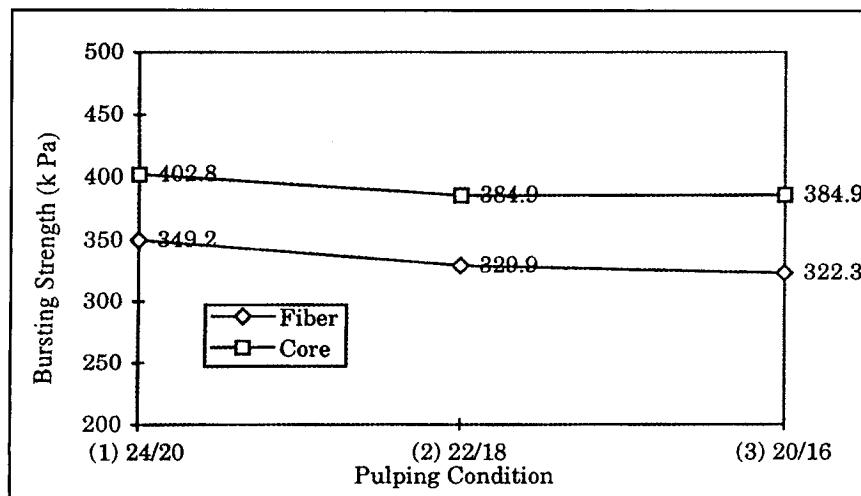


Figure 23.4. Changes in bursting strength.

Burst Index, $\text{kPa}\cdot\text{m}^2/\text{g}$

Decreased as the pulping condition became weak (Figure 23.5).

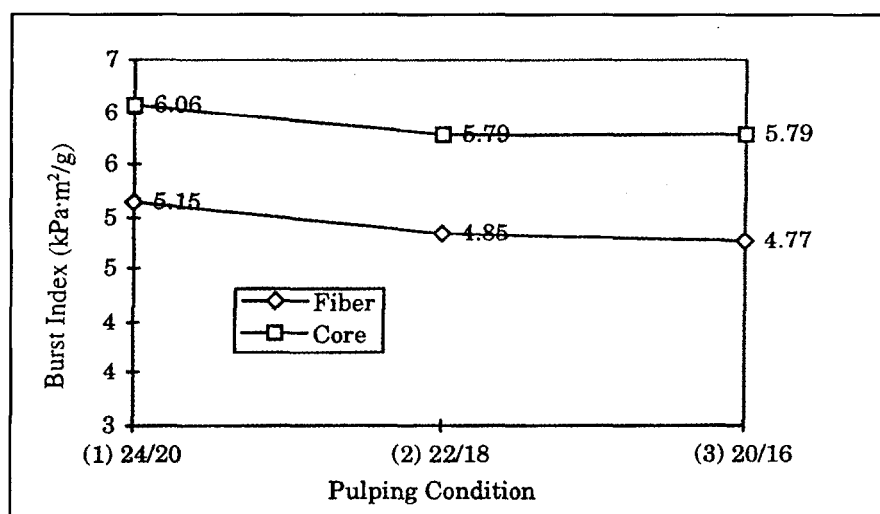


Figure 23.5. Changes in bursting index.

Tear Strength (Resistance), mN

Test results indicate that paper made from core fiber is noticeably weaker than paper made from bast fiber. In addition, tests conducted by Voest-Alpine indicate that paper made from the whole stalk is weaker than paper made only from bast fiber.

Tear Index, $\text{mN}\cdot\text{m}^2/\text{g}$

Paper made from core fiber was noticeably weaker.

Smoothness (Sheffield Units) SU or mL/min

Smoothness is a measure of the surface contour of paper. Contrary to the tear resistance and tearing index, core papers are superior in this regard.

Fiber Length, mm (Kajaani)

The bast has long fibers and the core has short fibers.

There was a tendency that milder pulping condition did less damage to the fiber length, especially in the bast fiber (Figure 23.6). Figures 23.7-23.10 show weighted and population distribution for C- 108 cultivar core fiber and bast fiber pulped with 24% Na_2S /20% NaOH .

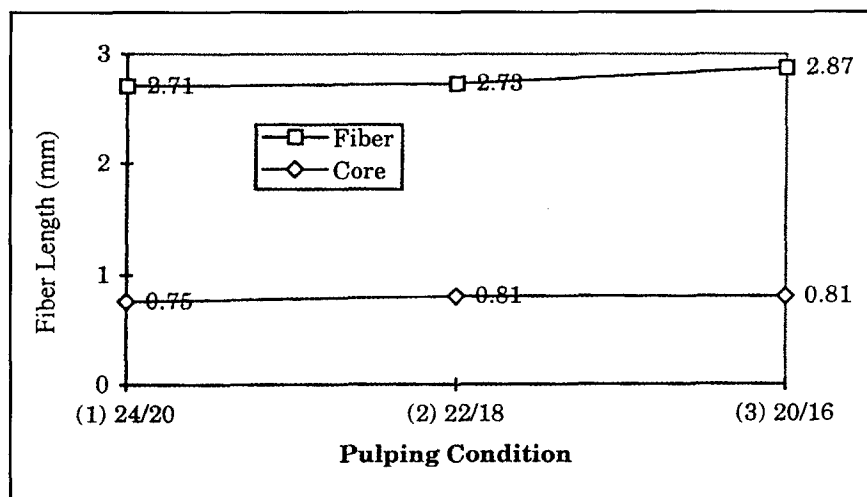


Figure 23.6. Changes in fiber length.

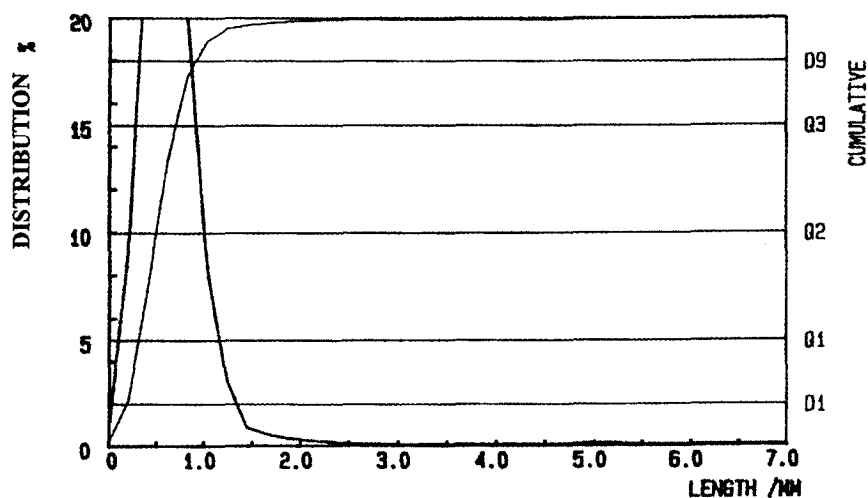


Figure 23.7. Kraft pulped, 24% Na_2S /20% NaOH , C-108 core fiber, weighted distribution.

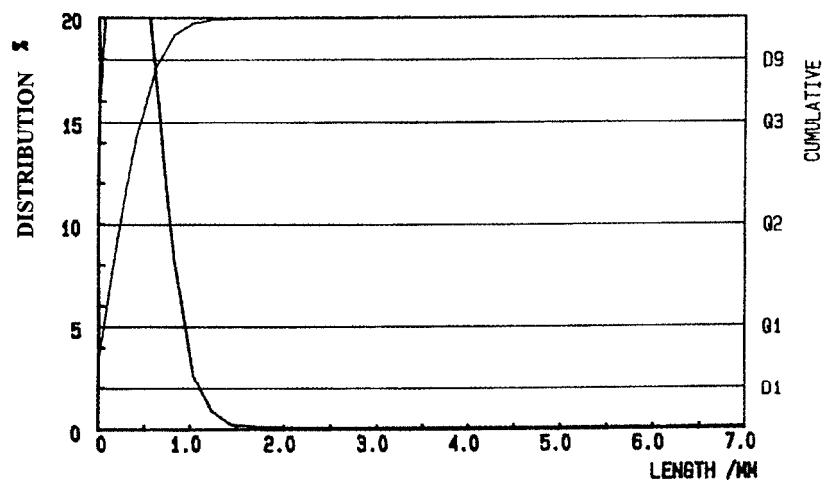


Figure 23.8. Kraft pulped, 24%Na₂S/20% NaOH, C-108 core fiber, population distribution.

Total fibers: 7008

Char	Weighted	Arithmetic
D1	0.18	0.00
Q1	0.31	0.06
Q2	0.49	0.24
Q3	0.70	0.46
D9	0.91	0.66
AV	0.54	0.80
% 1	10.77	44.29<0.200

Analyzed by Kajaani FS-100

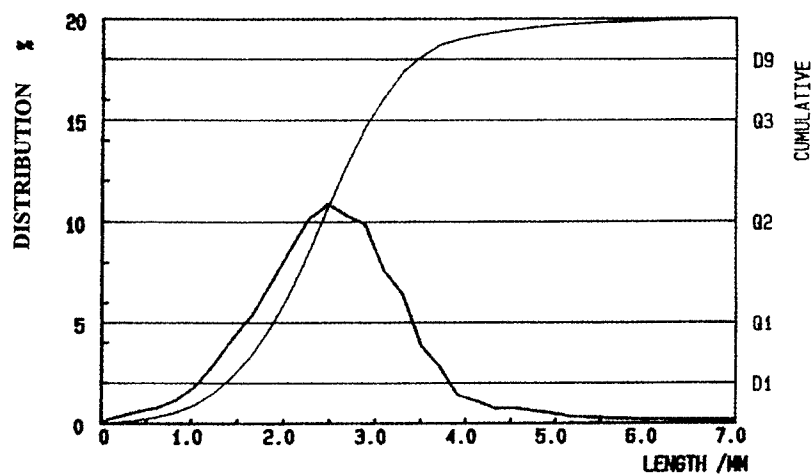


Figure 23.9. Kraft pulped, 24%Na₂S/20% NaOH, C-108 bast fiber, weighted distribution.

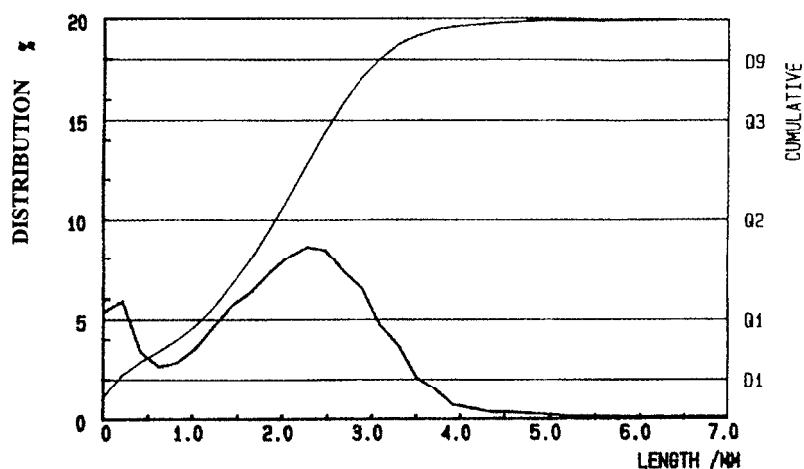


Figure 23.10. Kraft pulped, 24%Na₂S/20% NaOH, C-108 bast fiber, population distribution.

Characteristics

Total fibers: 4270

Char	Weighted	Arithmetic
D1	1.36	0.16
Q1	1.88	1.10
Q2	2.41	1.93
Q3	2.93	2.55
D9	3.45	3.07
AV	2.44	2.77
% 1	0.38	1.93/0.050
		11.01<0.200

Analyzed by Kajaani FS-100

CONCLUSIONS

- Paper made from bast fiber exhibit different physical properties versus paper made from core fiber.
- Paper made from core fiber is thinner and smoother than paper made from bast fiber.
- Paper made from bast fiber has a high tear resistance and tearing index.
- Due to their distinct physical properties, separate markets should be developed for paper made from bast fiber and core fiber, rather than to make paper from a mixture of both types of fibers. This separation would enhance the competitiveness of kenaf as an alternative raw material in the paper industry.
- The minimum pulping condition for kenaf is 20% Na₂S and 16% NaOH. A pulping condition lower than 20% Na₂S and 16% NaOH may not yield pulp that can be made into handsheets unless higher temperatures and more vigorous conditions are applied.

DISCLAIMER

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