

Mechanical processing of kenaf for nonwovens

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ABSTRACT: *There is a renewed interest in the utilization of kenaf (Hibiscus cannibinus L.) as an agricultural commodity. A myriad of projects throughout the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (USDA) have been initiated to find new value-added uses for both the fiber and core materials of the kenaf plant. Our objective is to incorporate kenaf fiber into nonwoven constructions. This research was designed to evaluate various methods of mechanical processing to obtain fibers acceptable for processing into nonwoven products. Cotton ginning equipment and a Rando cleaner were effective in reducing core material to less than 0.2% in two sources of kenaf.*

KEYWORDS: *Analysis, bark, cores, kenaf, mechanical treatment, nonwovens, processing.*

Kenaf, native to India and Africa, has been used as a natural source of fiber for hundreds of years. It was first introduced to the United States on a commercial scale in the early 1940s as the demand for jute fiber exceeded the supply when World War II began. Kenaf fibers were used primarily to make cordage, rope, and burlap cloth (1). Research on kenaf by the USDA/ARS began as early as 1956 (2). Through 1986, this research concentrated on the use of kenaf as a supplement to wood pulp. Even today, one of the major values of kenaf is as an alter-

nate fiber for the pulp and paper industries (3). Uses for kenaf vary widely. Even the leaves and stems of the kenaf cultivars have potential as livestock feed (4). Dried leaves contain 30% crude protein—compared with alfalfa's 16–21% (5). In some cases, emphasis has centered on the utilization of the core of the plant rather than the outer bast fiber. Kenaf core has been utilized as packaging material, animal bedding, oil sorbents, and poultry litter (6). A review of ongoing research in the USDA/ARS has been reported by Werber (7), and market assessments

of current and other potential uses for kenaf have recently been presented (8, 9).

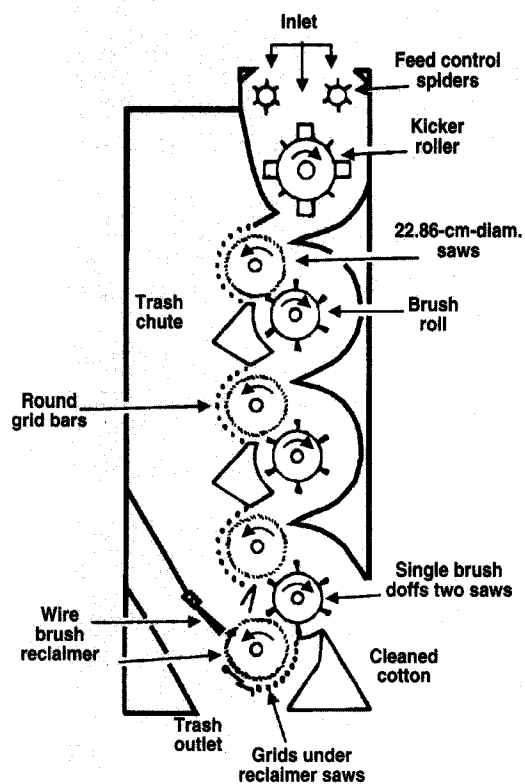
Improvements in the growing, harvesting, and mechanical separation of fiber and core have made fiber available at a reasonable price. However, additional research is still needed to develop new processes and improved products. One area that offers opportunity is the incorporation of kenaf fiber into nonwoven constructions.

Over 907,200 metric tons of fibers are used annually in the nonwovens industry. It is an industry dominated by synthetic fibers. Polyolefins, polyesters, and rayons are the three leading fibers used in the manufacture of U.S. nonwoven fabrics today. Research is needed to demonstrate that kenaf fiber can be used in nonwoven constructions at the same level or with properties superior to those of other fibers. There is great potential for the incorporation of kenaf fiber into the growing market of nonwovens.

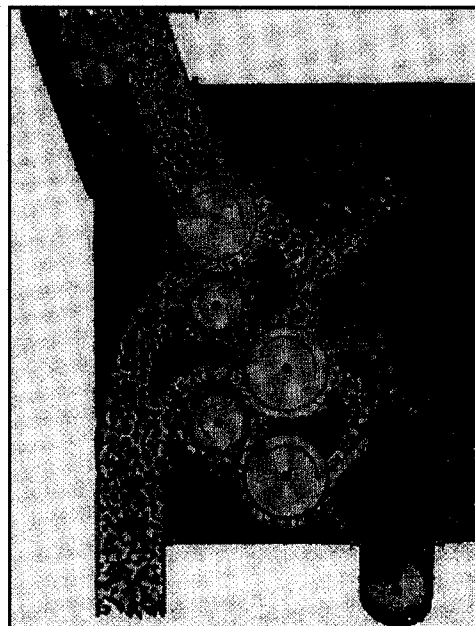
A kenaf processing facility is located in Jeanerett, LA, where it is grown as a rotational crop with sugarcane. Research on kenaf meets the overall objectives of the Southern Regional Research Center: the development of scientific information and technology to add value to crops. Successful development of useful and novel nonwoven fabrics that contain a high percentage of kenaf will result in the increased utilization of kenaf fiber, thereby enhancing markets for U.S. farmers.

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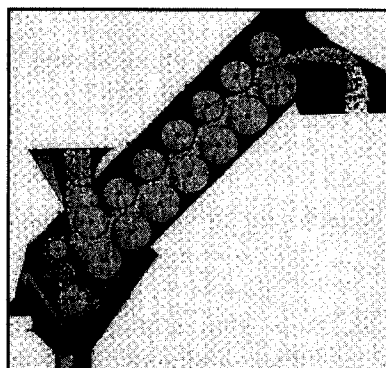
1. Cotton ginning equipment used to process kenaf



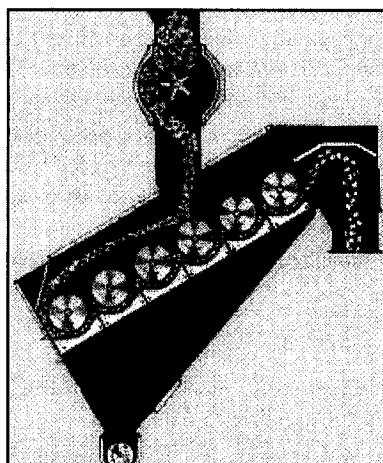
A: Stick machine



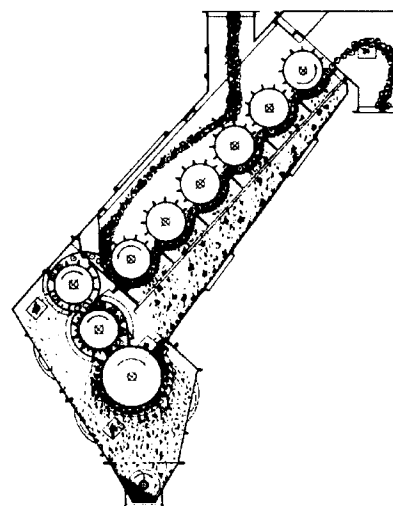
B: Standard stick machine



C: Impact cleaner



D: T30 trash master



E: T45 trash master

Kenaf Fiber

Kenaf has a bast fiber, which contains approximately 75% cellulose and 7% lignin, and offers the advantage of being biodegradable and environmentally safe. The bast fiber is actually a bundle of fibers bound by lignins and pectins. Therefore, for the purpose of discussion throughout this paper, it is necessary to define the following terms:

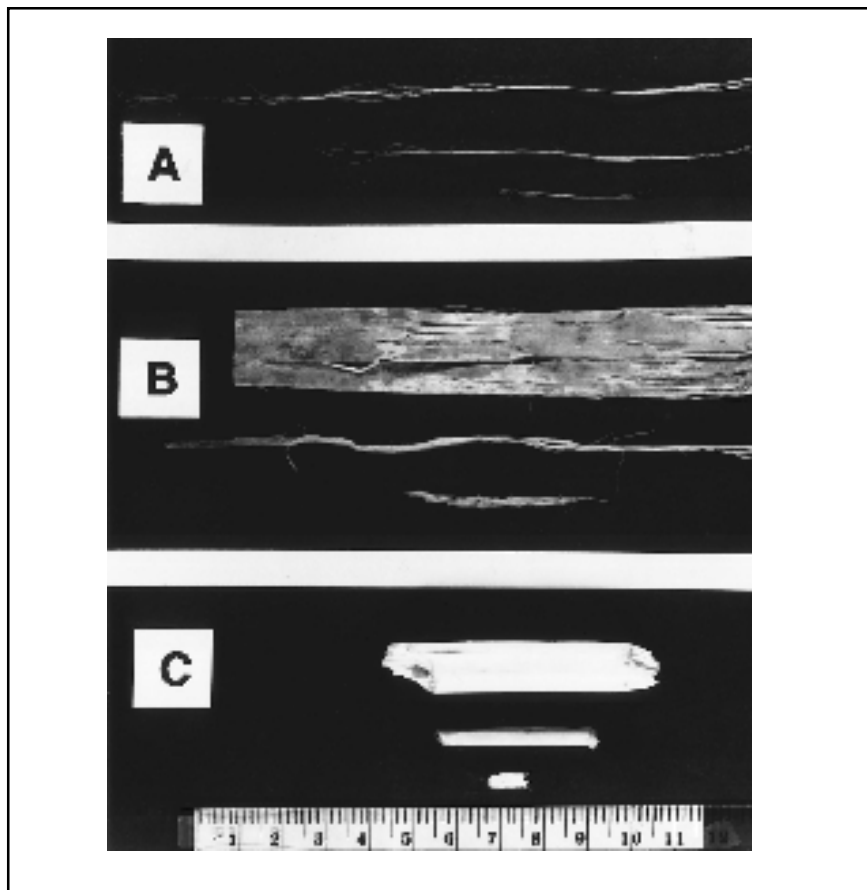
- “Fiber” is a strand of fine fibers that we have judged to be suitable for processing into nonwoven batts.
- “Bark” is a much larger bundle of fibers and has a woody appearance and feel.
- “Core” is the pith, a spongy tissue located below the bark of the plant.
- “Fiber stock” is the bast fiber as received from the processing plant after separation from most of the core material.

Our objective was to evaluate various methods of mechanical processing to obtain suitable fibers for processing into nonwoven products. At present, emphasis has been directed to the use of raw kenaf fiber, i.e., kenaf that has not been subjected to wet processing. Most uses for raw kenaf non-wovens would involve industrial applications such as filters, materials for cleaning up oil spills, geotextile structures, and agricultural mats. The possibility exists for further refinement of fiber for utilization in lighter-weight and better-quality nonwoven fabrics for use in apparel and household products.

Materials, equipment, and methods

Kenaf fiber stock was obtained from two field sources. Louisiana kenaf (LA) was obtained from Natural Fibers of Louisiana, Inc., P.O. Box 650, Jeanerette, LA 70544. California kenaf (CA) was obtained from ARGO-Fibers, Inc. P.O. Box 577, Corcoran, CA 93212.

2. Kenaf bast fiber, bark, and core. A = fiber, B = bark, C = core.



Equipment description

The Rando cleaner is a roller-type cleaner equipped with fine saw-tooth wire. The Rando webber is an air-laid machine used to produce fiber batts for nonwoven products. (The mention of companies or commercial products does not imply recommendation or endorsement by the USDA to the exclusion of others that may also be suitable.)

Original setup on webber included:

- Lickerin roll: 5 teeth/2.54 cm x 8 threads x 8 starts
- Feed roll: surface wound with Hollingsworth fine wire
- Nose bar: tight and smooth with high profile.

Modified setup on webber included:

- Lickerin roll: 2.7 teeth/2.54 cm x 8 threads x 1 start

- Feed roll: coarse diamond knurl; 14 pitch, 56 flutes
- Nose bar: loose and smooth with round profile.

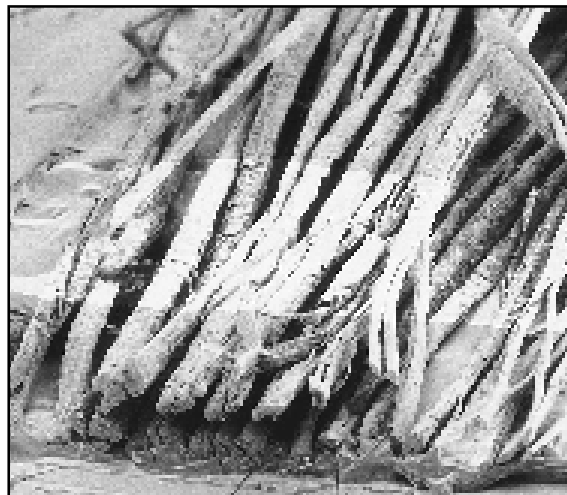
The equipment shown in **Fig. 1** was used at the Agricultural Research Service Cotton Ginning Laboratory in Soneville, MS:

- S = Stick machine with four 22.86-cm-diam. saws (Fig. 1A)
- S1 = Standard stick machine with three 35.56-cm-diam. saws (Fig. 1B)
- S2 = Standard stick machine with three 35.56-cm-diam. saws with Plexiglas
- I = Impact cleaner (Fig. 1C)
- T30 = Trash master: a six-cylinder incline cleaner with 1.27 cm space between grid bars and 30° incline (Fig. 1D)

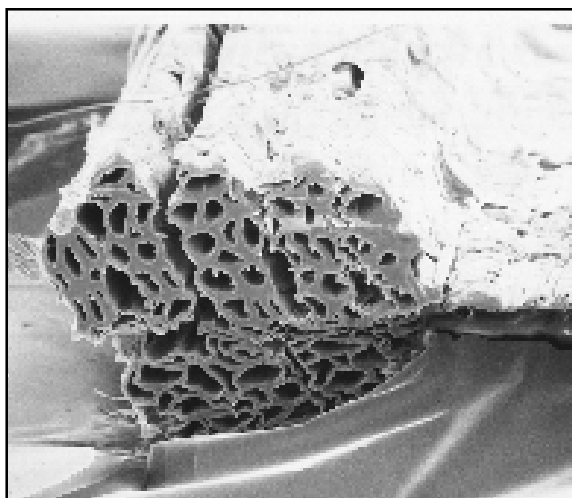
3. Photomicrographs of kenaf fiber and bark



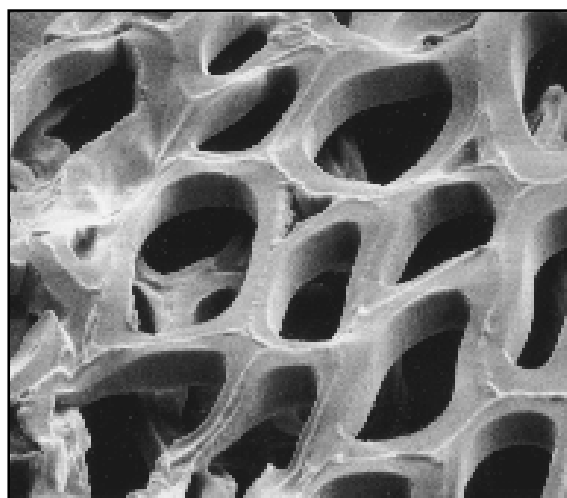
A: Kenaf fiber, 30 x



B: Kenaf bark, 30 x



C: Kenaf fiber, 400 x



D: Kenaf fiber, 3000 x

T45 = Trash master: a six-cylinder incline cleaner with 1.91 cm space between grid bars and 45° incline (Fig. 1E)

Two bales of Louisiana kenaf were processed through various types of machinery at Stoneville. The cleanest kenaf fiber (less core) was produced from a processing sequence of T30-S1-S2-T45 as listed above. Fiber stock from this series was labeled "Stone."

Abbreviations:

LA = Louisiana kenaf fiber stock as received

LA-H = LA kenaf processed through hammermill in Jeanerette, LA

CA = California kenaf fiber stock as received

Stone = LA processed on cotton ginning equipment in Stoneville, MS

1X = One pass through the Rando cleaner

2X = Two passes through the Rando cleaner

W = Waste from Rando cleaner

Web-O = Processed through webber with original rolls and nose bar

Web-M = Processed through webber with modified rolls and nose bar.

Analysis

Two 50-g specimens were randomly removed at various stages of processing for each kenaf sample. After equilibration, each specimen was

Kenaf Fiber

manually separated into fiber, core, and bark and the average percentage of each determined.

Needlepunching

Nonwovens were produced on a Morrison Berkshire needleloom equipped with a single 31.8-cm board containing 575 needles. The needle design was 15 x 18 x 40 x 3.5-F222-G92919 supplied by Groz-Beckert. Batts were processed at a linear speed of 1.83 m/min, 186 penetrations/cm², and 229 strokes/min.

Fabric testing

Fabric weight was determined from six specimens each (2.54 cm x 17.78 cm) from the machine direction (MD) and cross direction (CD) systematically selected throughout the fabric. These same specimens were used to determine breaking strength and elongation (10a). Inflated diaphragm was used for bursting strength (10b). Stiffness, reported as bending moment, was obtained by the Tinius Olsen method (11a). Fabric thickness was determined with a Randall and Stickney gauge at 3.58 g/cm² pressure (11b).

Discussion

Previous investigations into the mechanical processing of kenaf have concentrated primarily on the separation of core material from the outer bark fiber. The ratio of bark to total stalk is useful information for efficient yields, particularly if the bark fiber is the focal point of the production process (12). The methods employed for separating bark fiber from core have been sufficiently covered by Fuller and Doler (13) and will not be addressed here.

Fiber stock as received from the processing plant is crude and often sent to paper mills as a source of pulp. Little attention has been directed to mechanical means of improving fiber quality for other uses. Ramaswamy *et al.* studied differences in fiber quality between vari-

eties of kenaf, but in these studies fibers were bacterially or chemically retted (14). Unlike cotton fiber, no grading system is available for determination of kenaf fiber quality. Our investigation was an initial attempt to establish fiber standards and was directed to a differentiation of fiber stock, as supplied from a kenaf processing plant, and mechanically-processed fiber which might be suitable for use in nonwovens. Representative samples of these materials are shown in Fig. 2. It is readily seen that these materials cover a wide range of sizes, particularly bark and core.

The photomicrographs in Fig. 3 place the terms fiber and bark, as defined earlier, in perspective. The fiber strand (Fig. 3A) is compared to a cross-section of a bark sample (Fig. 3B), which contains several strands of fibers. Figures 3C and 3D show the fiber strand at 400X and 3000X magnification, respectively. Each circular area represents the ultimate single fiber of kenaf. The material that links the fibers is depicted by the ridges running along the center of the fiber walls.

Processing

The analysis of various kenaf samples was conducted after all processing was completed. Results from analysis will be discussed later. The following is a chronological narrative of the different methods of processing.

Because of the proximity to our laboratory, kenaf fiber stock was obtained from Jeanerette, LA. This material appeared to be too coarse for processing into nonwoven batts through an air-laid machine. The initial objective was to remove core material and hopefully reduce the bark portion to a more fibrous material. To this end, LA kenaf was processed through a hammermill with a 2.54-cm-diam. screen (LA-H). Kenaf from this process gave short fiber, and core material was still prevalent.

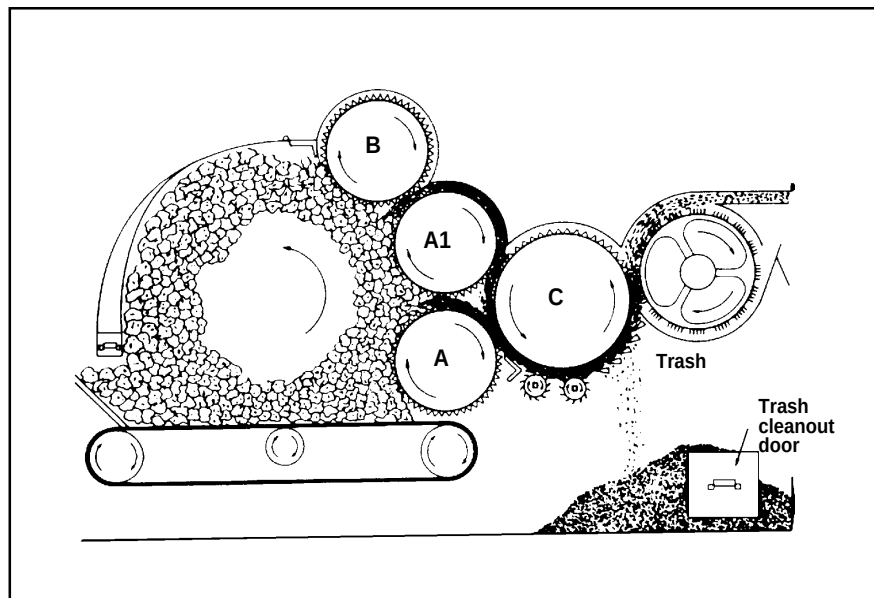
An attempt was then made to process LA kenaf through a Rando cleaner, as shown in Fig. 4. However, the saw-tooth wire around the cylinders became packed with core material. The wire around cylinder C (Fig. 4) was particularly susceptible to loading of core material. This required frequent shutdowns to clean the wired cylinders. The kenaf fiber was too coarse and contained too much core. It was evident that this machinery alone could not be used for cleaning LA kenaf.

The next approach was to process LA kenaf through the cotton ginning equipment described in the materials, equipment, and methods section. The following sequences of equipment were tried:

1. S2: Too much core remained in the fiber stock.
2. S2/I: Too much core remained in the fiber stock.
3. S: Removed core better than no. 1 or no. 2, but long fibers wrapped around cylinders and presented processing problems.
4. S2/T30/T45/I: Core still present but much better than no. 1–no. 3.
5. S1/S2/T45: Not as thorough as no. 4.
6. T30/S1/S2/T45: Best removal of core material.

The major objective was to reduce the amount of core in the LA kenaf. The presence of core for each of these processes was easily discernible by visual inspection. The process that yielded the least amount of core was the sequence used in run no. 6. Kenaf processed by this sequence was labeled "Stone." Two additional runs (no. 7 and no. 8) were made using the same sequence as in run no. 6 to provide three replicates. The yield in kilograms of processed kenaf and waste for the three runs were 61%, 64%, and 62%, respectively, and the average waste was 31.8%. The data below the line in Table I is the amount of waste re-

4. Rando cleaner



I. Kenaf yield and waste from "stone" processing sequence

	Run no. 6, kg	Run no. 7, kg	Run no. 8, kg
Raw stock	63.23	45.24	43.05
Yield	38.82	28.94	26.82
Total waste	19.72	13.88	14.41
Loss	4.69	2.42	1.82
T30 waste	3.46	2.80	3.04
S1 waste	7.45	4.84	5.07
S2 waste	4.02	2.59	2.65
T45 waste	4.79	3.65	3.65

moved by each of the four machines for each run. The percentage of waste removed is graphically depicted in **Fig. 5**. In each of the three runs, the standard stick machine (S1) removed the greatest percentage of waste (average 11.4%), followed by the trash master (T45). An average of 5.7% material was lost during processing. This unrecovered material was attributed to hang-up in the equipment, fly, possible changes in moisture content, and experimental error.

The stick machine (S1) did a good job in removing large pieces of core, and the incline cleaner, with 1.95-cm grid-bar spacing, was successful in

removing smaller pieces of core. However, the processing sequence of run no. 6 was not entirely successful. Although most all core material had been removed, the process was not selective enough because a moderate amount of fiber stock was also removed in the waste. Samples of the waste fraction from each of the three runs were analyzed for core and fiber stock. **Figure 6** shows that the total waste actually contained more fiber stock (average 54%) than core (average 46%). Also, the recovered fiber stock still contained large bundles of fiber, i.e., bark. All of this recovered stock did not appear suit-

able for processing in nonwovens equipment.

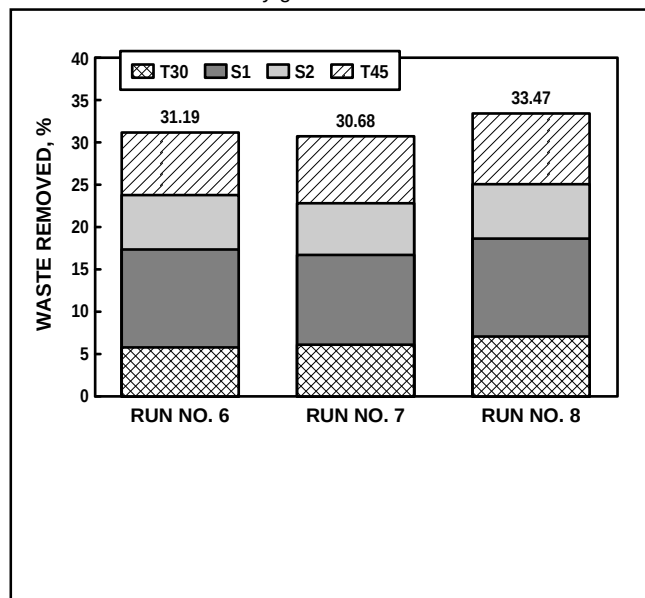
At this point in the evaluation, another source of kenaf became available from California. Subjective evaluation indicated that this kenaf contained much less core than LA kenaf. In fact, the CA kenaf was nearer in quality to the LA kenaf after processing through cotton ginning equipment, i.e., Stone kenaf. Analysis of Stone and CA kenaf will be discussed later.

It was now feasible that these two sources of kenaf, Stone and CA, might be cleaned further by processing through the Rando cleaner. Both were processed through the Rando cleaner one time (1X) and two times (2X). **Table II** shows the weights of processed kenaf and waste (W) after each pass. Considering each pass as a separate process, the yields of recovered fiber stock from Stone-1X and Stone-2X were 66.2% and 70.1%, respectively. Overall yield of fiber stock through two passes was 46.4%. The CA kenaf gave noticeably better yield of fiber stock than did the Stone kenaf. After 1X and 2X the yields were 78.6% and 80.0%, respectively. The theoretical overall yield through two passes was 62.9%.

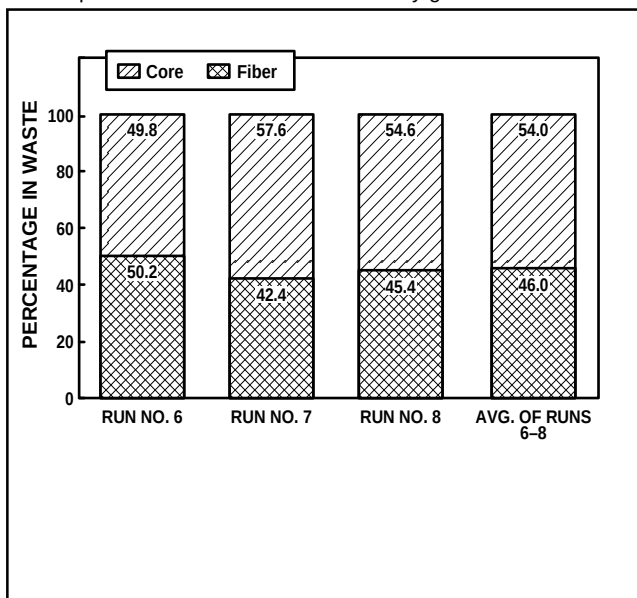
The Stone-1X, Stone-2X, CA-1X, and CA-2X kenafs appeared to be of sufficient quality to warrant processing through the air-laid Rando webber for preparation of nonwoven batts. Earlier attempts to prepare batts on the webber from cruder samples of kenaf had resulted in core loading on the feed and lickerin rolls. It was later modified with a different nose bar, feed roll, and lickerin roll. The modification was designed to reduce damage to kenaf fiber, thus making it more suitable for nonwovens. **Figure 7** depicts the difference between the two Rando webber setups.

Over 500 g each of Stone-1X, Stone-2X, CA-1X, and CA-2X kenafs were processed through the webber with the original setup (Web-O). Another 500 g of each kenaf sample

5. Kenaf waste removed by gin machines



6. Components of kenaf waste removed by gin



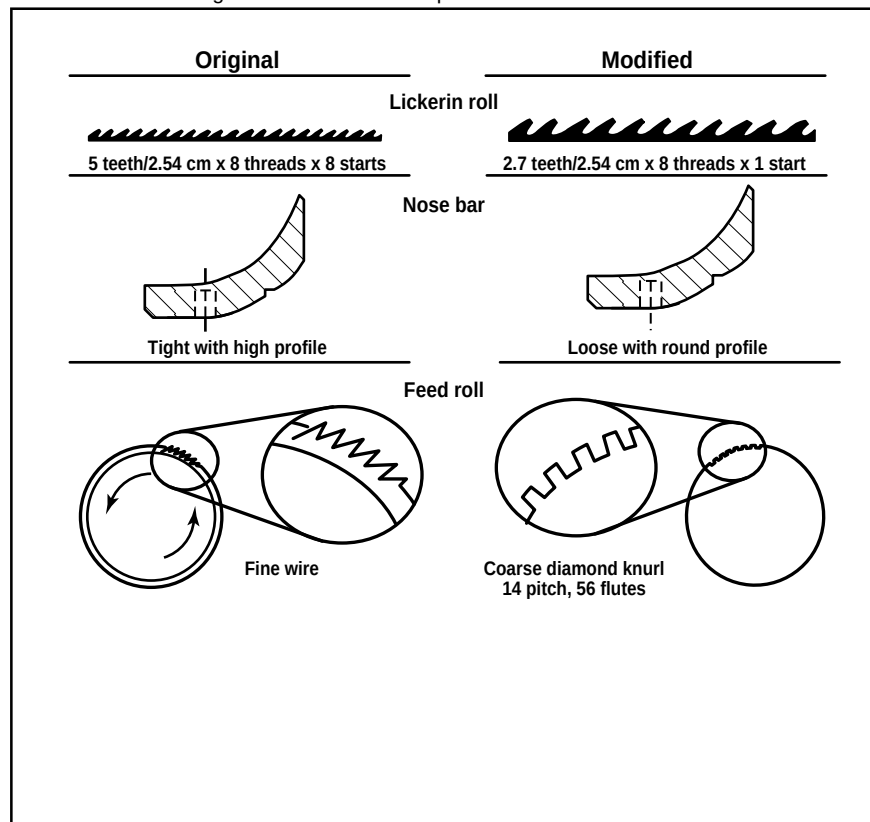
was processed through the modified setup (Web-M). The hopper and webber were thoroughly cleaned before processing each sample of kenaf. Analysis of the samples from air-laid processing preparation of nonwoven mats are discussed below.

Analysis

Kenaf samples from the various stages of processing were manually separated into three segments. The percentages of fiber, core, and bark in each sample are shown in **Table III**. The core was readily discernible from fiber and bark. However, separation of fiber from the "finer" bark was more subjective. Trash, which was minimal, was any extraneous material and consisted primarily of kenaf fines (dust). For analysis, anything not classified as fiber or core was combined with bark.

It is obvious why the LA kenaf (no. 1), which consisted primarily of bark (69.9%) and core (28.2%) material, caused processing problems as described above. Analysis also shows that the hammermill process (no. 2), performed at the Jeanerette facility, was not effective in removing enough core. Although more than 50% of core material had been re-

7. Rando webber: original and modified setups



moved, 13.9% was still too much for efficient processing through nonwoven equipment.

Two passes directly through the Rando cleaner (no. 3) reduced the

amount of core to 0.1%, but this was a tedious and laborious operation since the cylinder wire had to be cleaned several times throughout the process. The cleaner alone was sim-

II. Processing of kenaf through Rando cleaner

	<i>Original wt., kg</i>	<i>Fiber wt., kg</i>	<i>Waste wt., kg</i>
Stone			
1 Pass	21.23	14.06	7.17
2 Passes	9.57	6.71	2.86
California			
1 Pass	15.88	12.48	3.40
2 Passes	7.94	6.35	1.59

III. Analysis of kenaf after various processes

<i>Sample no.</i>	<i>Description</i>	<i>Fiber, %</i>	<i>Core, %</i>	<i>Bark, %</i>
1	LA	1.9	28.2	69.9
2	LA-H	60.6	13.9	25.4
3	LA-2X	87.2	0.1	12.6
4	Stone	43.0	1.1	56.0
5	CA	35.7	2.2	62.1
6	Stone-1X	87.7	0.1	12.2
7	Stone-2X	89.0	0.2	10.8
8	Stone-1X-W	59.2	3.3	37.6
9	Stone-2X-W	65.4	0.4	34.2
10	CA-1X	84.3	0.2	15.5
11	CA-2X	89.5	0.1	10.4
12	CA-1X-W	50.2	15.4	34.4
13	CA-2X-W	68.9	1.9	29.3
14	WEB-O, Stone-1X	91.2	0.1	8.7
15	WEB-O, Stone-2X	91.6	0.2	8.2
16	WEB-O, CA-1X	88.3	0.4	11.3
17	WEB-O, CA-2X	91.4	0.2	8.4
18	WEB-O, CA	81.4	1.8	16.9
19	WEB-M, Stone-1X	87.9	0.1	12.0
20	WEB-M, Stone-2X	89.5	0.1	10.4
21	WEB-M, CA-1X	85.2	0.4	14.3
22	WEB-M, CA-2X	91.8	0.1	8.1
23	WEB-M, CA	73.7	1.6	24.7

ply unsuitable as a practical process for this crude product. Processing LA kenaf through the cotton ginning equipment in Stoneville proved to be a viable alternative since core

was reduced from 28.2% to 1.1% (no. 1 vs. no. 4) without processing problems. In deference to the Jeanerette, LA, company as to the crude quality of kenaf fiber, we should mention

that the objective of this facility was the production of core material. The core was recovered in three different grades of high-quality products free of fiber, bark, and trash. The fiber, bark, and unrecovered core are by-products that were sent to a pulp mill.

Analysis in Table III shows that the percentage of core in Stone (no. 4) and CA (no. 5) kenaf were approximately the same, i.e., 1.1% and 2.2%, respectively. A subsequent one pass (no. 6 and no. 10) through the Rando cleaner reduced the percentage of core to less than 0.2% and also increased the percentage of fiber by reducing the amount of bark. A second pass (no. 7 and no. 11) increased the percentage of fiber only slightly. The core and bark removed from these cleanings were concentrated in the waste fractions (no. 8, no. 9, no. 12, and no. 13). These waste samples also contained a large percentage of fiber (50.2–68.9%). However, fiber from the waste was noticeably shorter in length than the output fibers. These shorter fibers were the result of fiber damage and shredding of bark material. An ideal cleaning process would be one that is more gentle while selectively removing only core.

Kenaf processed through the webber with original equipment (WEB-O), compared to the respective kenaf processed through the webber after modification (WEB-M), consistently had a greater percentage of fiber and less bark (no. 14–no. 18 vs. no. 19–no. 23). In all WEB-O samples, the percentage of fiber increased while lowering the percentage of bark. This was attributed to the finer teeth on the lickering roll and the feed roll on the WEB-O (Fig. 7), which would be more likely to break up bark material. However, the WEB-O would present more processing problems than WEB-M during long-term processing if the kenaf contained high concentrations of bark. For example, CA kenaf (no. 5) containing 62.1% bark was successfully processed through the WEB-O

IV. Nonwoven mats of kenaf/rayon blends

Sample	Rayon format	Percent kenaf	Fabric wt., g/m ²	Breaking strength, N		Elongation, %		Stiffness ($\times 10^{-5}$ N·m)		Bursting strength, kPa	Thickness, mm
				MD	CD	MD	CD	MD	CD		
A	Batt sandwich	87.0	366	12.09	2.59	35.6	61.0	576	496	360.8	5.24
B	"Needled-batt" sandwich	86.7	335	7.61	1.60	28.5	62.0	405	311	280.4	6.54
C	Scrim sandwich	91.0	351	1.54	0.64	22.9	30.4	231	258	91.9	5.48
D	Scrim "club-sandwich"	86.8	374	3.77	1.52	25.6	42.9	407	384	179.3	6.14

(no. 18) and the WEB-M (no. 23), resulting in more fiber and considerably less bark. However, a lickerin roll and feed roll on WEB-O had a noticeable buildup of bark material even on a relatively short run. There was no buildup on WEB-M during the same run time.

Nonwoven mats

A preliminary investigation was conducted on the fabrication of nonwovens containing kenaf fiber. Kenaf batts, prepared on the Rando webber using the modified setup (WEB-M), were layered with rayon and needlepunched. Four laminated mats were prepared as follows:

- Rayon fiber batts were prepared by carding. Batts were placed on top and on the bottom of a kenaf batt, then needlepunched together.
- Rayon batts were carded and needlepunched before placing on top and on the bottom of a kenaf batt, then needlepunched together.
- A commercial spunbonded cupra rayon scrim ("Belise" from Asahi Chemical Industry Co., Ltd.) was placed on top and on the bottom of a kenaf batt, then needlepunched together.
- Same as "C" except scrim was placed above, below, and between

two kenaf batts, then needlepunched together.

Physical properties obtained on the laminated mats, as described above, are shown in **Table IV**. Breaking and bursting strengths of the mats prepared with fiber, in batt form (A) or as a needled-batt (B), were greater than mats prepared using the rayon scrim. Bursting strengths for A and B were 292% and 205%, respectively, greater than C. The addition of a third scrim layer (D), to make the percentage of rayon comparable to the fiber blends, gave increased breaking and bursting strengths. But this "Club sandwich" was still weaker than the fiber blends A and B. The greater strength of the fiber laminates was attributed to greater fiber to fiber friction between rayon and kenaf. The rayon fiber format allowed for easier transport of fibers into the kenaf batt than did the more structured rayon scrim. The fiber-batt sandwich gave greater strength than the needled-batt sandwich. Preneedling of the rayon batt before needling with kenaf apparently inhibited movement of rayon fiber through the kenaf batt. The high ratio of MD/CD breaking strength was attributed to anisotropic orientation of rayon fibers during the carding process.

Mats of 100% kenaf could not be successfully needlepunched because air-laid kenaf batts were not very sturdy and were difficult to handle.

Rayon webs above and below the kenaf batt provided a good stable structure for the needlepunch process. Essentially all of the strength of these mats was derived from the addition of rayon.

An intimate fiber blend of kenaf and rayon was not included in this preliminary investigation. A high-kenaf blend ratio was desired, and it was difficult to obtain good uniform distribution using only 15% rayon fiber with a much larger portion of kenaf. Layering of fiber webs or scrims to form laminates provided a better means of obtaining good uniformity. Additional inference from data in Table IV should not be attempted since this was only a preliminary attempt to prepare nonwovens from the processed kenaf. Quality of batts and fabrication of improved kenaf nonwovens will be the subject of further investigation.

Conclusion

Various methods of cleaning and processing of kenaf were demonstrated. The quality of fiber produced by these methods was suitable for processing into nonwoven mats. Although quality fiber was obtained by these methods of processing, improved equipment and processes are still needed to obtain better efficiency while maintaining optimum fiber quality. If kenaf is to eventu-

ally become a value-added crop, consideration should now be given to the establishment of a grading system in a manner similar to cotton. An initial step would be to develop an objective instrumentation method for determining the percentages of core and bark material in a bale. This analysis will ascertain the amount of cleaning required for final end-use production. Average fiber (strand) dimensions, i.e., length and width, will be a major consideration affecting final properties of nonwoven fabrics or composites. Ideally, a fiber length/thickness distribution curve could be generated for kenaf samples. The ultimate objective will be to evaluate usable fiber for processing into nonwovens. The work presented in this paper was an attempt to initiate this process. 

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