KENAF FIBERS FOR AUTOMOTIVE NONWOVENS

D. V. Parikh, T. A. Calamari and A. P. S. Sawhney
Southern Regional Research Center, USDA
New Orleans, LA
Mary Warnock
University of Arkansas
Fayetteville, AR

Abstract

Kenaf bast fibers are derived from bark of the Hibiscus Cannabinus L plant. The fibers are biodegradable, renewable and environmentally benign. Demand for moldable nonwoven fabrics containing kenaf for automobile interiors is increasing.

Raw kenaf fibers consist of coarse bundles of single fiber cells glued together by lignin and pectin in a meshwork of interconnected single fibers. These fibers have to be chemically retted and refined. To efficiently card the fibers on a cotton card some of the binding glue (lignin and pectin) has to be removed so that the resulting fibers will have bundle fragments that are fine enough to card. Continuing research efforts at SRRC have resulted in a simplified chemical retting of mechanically harvested fibers. Chemical retting procedures have been developed for two distinctly different varieties of kenaf, namely, Forage harvested Tainug-2, 1.5-3 inch short fibers supplied by Mississippi State University, and naturally retted Cultivar Everglades-41, 40"-50" long ribbons supplied by University of Arkansas. Development of chemical retting procedures is expected to provide guidelines for retting of any kenaf variety.

In addition to chemical retting and the application of a card-finish to the fibers, certain properties of needlepunched thermoformable composites made with kenaf and other vegetable fibers for auto interiors are also described. Chemically retted and finished kenaf fibers were processed in combination with other fibers such as greige cotton, recycled polyester and polypropylene.

KEYWORDS: Kenaf: Tainug-2, Everglades- 41, Bark, Core, Chemical Retting, Soap Finish, Carding, Moldable Nonwoven Composites, Automobile Interiors, Cotton Fines (cotton waste), Jute, and Flax.

Introduction

Kenaf fibers are derived from bark of the Hibiscus Cannibinnis L plant. The plant consists of an outer fibrous bark and an inner core. [Figure 1a. shows the cross-section of the plant. 1b. Shows bark, bast and core fibers. 1c. shows bast and core fibers. 1d. shows core fibers and 1e. shows bast fibers]. The fibers need to be separated into bast and core fibers. Core fibers find use as an absorbent to clean up oil spills and as raw material for pulp in nonwood paper [1, 2]. The bast fiber ribbons are used primarily to make twines, cordage and rope, and recently as textile fibers in apparel and nonwovens [3, 4].

The bast fibers are constructed of thick-and-thin walled single-fiber cells (length: 2 to 7 mm, and diameter: 10 to 30 μ m) that are overlapped and glued together by noncellulosic materials (lignin, pectins, and hemicellulose) to form continuous ribbons, Figure 2 [5]. The ribbons may run the entire length of 10 to 14 ft of the plant stem. Under a microscope, the fiber cells appear as long cylindrical tubes which may be striated lengthwise, but are without convolutions.

Kenaf plants can grow to a height of 10 to 14 ft in 5 to 6 months, which make them an abundant, renewable resource. Their bast fibers offer the advantage of being biodegradable and environmentally benign. The harvested stems are decorticated to yield kenaf fiber. Because of the coarseness and stiffness of the bast fiber bundles, they can be carded only through a coarse wool system or through a modified cotton card [6,7]. For the fibers to be carded on a cotton card, it is necessary to remove controlled amounts of the binding glue and make the fibers sufficiently fine and pliable. By controlling the lignin and glue that are removed, it should be possible to obtain fibers that are suited to the cotton carding system. The present research is a continuation of the earlier work of SRRC to develop and demonstrate an economical route of making kenaf fibers suitable for carding on a cotton system.

The present work includes the chemical retting (caustic extraction) process and application of a card finish to two distinctly different varieties of kenaf, which have very different agricultural, harvesting and processing histories. This report describes a pilot plant development for refining kenaf fibers. The development appears to have been brought to a level where it now produces repeatable results. It is at a stage ready for a scale-up, industrial run.

Moldable nonwoven automotive fabrics are currently made of synthetic fibers that are not easily biodegraded. Incorporating kenaf fibers in nonwoven fabrics may enhance biodegradabilty besides imparting greater acoustical insulation and reducing the weight of the vehicle. The nonwovens with kenaf fibers are 20% lighter than those from glass fibers because fiber density of kenaf is 1.4 g/cm^3 vs. 2.55 g/cm^3 for glass [8].

The market for moldable automotive nonwovens is large. With some 15 square meters of nonwovens used in the interior and trunk of an average automobile, and 15 million vehicles produced in a year, over 225 million square meters are used – not including trucks. Successful use of kenaf fibers in the nonwoven applications for making thermoformable composites for automobile interiors should lead to a considerable expansion in kenaf cultivation.

Previous Work

There are only a few references that specifically address cleaning and chemical retting of mechanically harvested short kenaf fibers. Ongoing work at SRRC has been reported by Moreau et. al. [9] and Tao et. al. [10]. Moreau systematically studied various mechanical methods of cleaning kenaf and determined that kenaf as received contained 32 % waste primarily of bark and core. Mechanically cleaned fiber (free from core and bark) was found suitable for processing through Rando webber (air-laid system) and needlepunching, but the fiber was not fine enough for processing on a card. Tao and co-workers went a step further and carried out caustic retting of the mechanically cleaned fiber so that the fiber would be suitable for processing on a card. The treatment conditions and loss in fiber weight due to caustic retting are reported in Table I. They concluded that kenaf fiber refined by treatment with 2N caustic solution for 3 hours was suitable for carding. Ramaswamy and her colleagues at the Mississippi State University have investigated the extraction of long and fine kenaf and have compared caustic retting with bacterial retting of long fibers [11, 12, 13].

Materials, Equipment and Methods

The two varieties of kenaf fibers studied were:

Tainug-2 (T-2). Kenaf fiber stocks were obtained in 400 pound bales from Mississippi State University [14]. The mature fiber plants were commercially harvested using machinery and methods adapted from other crops, namely, forage, cotton and sugarcane. This technique did not allow complete decortication and resulted in 1.5 to 3.0 inch short fiber stocks. "Fiber stock" may be defined as the bast fiber that had undergone mechanical separation from

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most of the core material. The T-2 supply, however, contained bark, core and vegetable debris of nearly 35%. Fiber stocks have generally been sent to paper mills as a source of pulp [9,10]. Adhering bark in any form results in downgrading the fiber and is not acceptable in fibers for carding. At SRRC, T-2 fibers were made free from bark and core by passage through a Rando cleaner. On mechanical cleaning, the brittle fibers became even shorter, at 1.0 to 1.5 inch. Chemical retting was studied at this stage of fiber. Incidentally, the T-2 bast fibers visually resemble peat moss fibers.

Everglades 41 (E-41). Fifteen pounds of filament ribbons, 40-50 inch in length, of kenaf E-41 were obtained from the University of Arkansas [15]. The kenaf stalks were harvested while they were green, decorticated, and naturally (bacterial) retted. Stalks were tied together in bundles of ten, weighted and submerged in water in large containers. Bacterial retting took place for 6 to 8 weeks, after which time the bark became soft and could easily be separated from the core by hand. The bundles were removed from the water and washed in high pressure water. The high pressure of water cleaned the bark of any slime and allowed it to be separated from the core. The fibers were dried in the open environment with air circulating around the fibers. The E-41 supply, however, contained nearly 13% of the bark or core fibers. Unlike T-2, these E-41 ribbons were pliable with high moisture content (13%), and did not require any mechanical cleaning. The resulting fibers were gold in color with a pleasing luster. The fibers, after chemical retting and finishing, were chopped to 2.0 to 3.0 inch length for processing into nonwoven fabrics.

Other Materials. Greige cotton fibers were obtained from Veratec, Colrain, Massachusetts. Bleached cotton fines, the waste from cotton swab manufacturing, were obtained from American White Cross, Dayville, CT. Recycled polyester, substandard polypropylene (PP), and jute were donated by Clark, Cuttler and McDermott, Franklin, MA. Flax was donated by Janesville & Co., Norwalk, OH. Substandard 56-11 spunbonded polyester scrim (130 gsm) was donated by Freudenberg, Durham, NC. Chemicals used were: caustic soda, acetic acid, anthraquinone, sodium bisulfite, (Fisher Chemical Co.), Strodex Super V8 (surfactant), an alkali stable wetting agent from Dexter Chemical Corporation, and rice soap donated by Veratec, Colrain, MA.

Nonwoven Composites

Needlepunched carded nonwoven fabrics were produced using refined (water boiled, and caustic extracted) kenaf fibers T-2, and E-41 along with (a) greige cotton, in weight percent ratio of 80:20, and (b) recycled polyester and PP in weight percent ratio of 35:35:30. Other vegetable fibers such as cotton fines (cotton waste from swab manufacturing), jute, and flax were used as received. Cotton-, jute-, and flax composites produced in the ratio of 35:35:30 were also studied for comparative evaluations. Composites of kenaf and other vegetable fibers were also made with PP in the weight ratio of 50:50. All fibers were opened in a Uster Spinlab Fiber Opener/Blender and blended as required, and the blended fibers were again passed through Fiber Opener/Blender to improve intimacy of the blend. Blended fibers were used to produce carded webs. Blended carded webs of kenaf and other vegetable fibers with recycled polyester, and PP (35:35:30) were needlepunched on spunbonded polyester scrim to produce new automobile nonwovens. With an air-laid system, the fibers were used without passing through Fiber opener/blender. Approximately 2000 to 3000 g of fibers in the desired composition were blended in a hopper of Rando Feeder-Webber in 1 hr of tumbling. Air-laid batts (45x10 cm width x thickness) were formed using the following machine potentiometer settings: conveyor = 100, feed 650 – 750, and apron speed =400. The feeder fan damper was set at open, and Webber fan was set 73 degrees on closed side. The batts were then cut in half (lengthwise), compressed by rolling under a tray, and then run twice through a Morrison-Berkshire needlepunch loom set at a loom width = 25 cm, needle board = 18 needles/cm-width (Groz-Beckert needles, 15x18x40x3 ½); operating cycles/minute = 228; speed = 180 cm/minute continuous feed; and penetrations/square cm = 46.5. There were four passes through the needlepunching loom and fabrics were turned over after each pass. Carded webs were also needlepunched in the way described. The resulting fabrics were trimmed and weighed to determine their area density in gsm.

Analysis

Two 25 g specimens were randomly removed from the fiber supply. Each specimen was manually separated into fibers, core, bark, and dust and the average percentage of each constituent was determined, Table II.

Evaluating Nonwoven Fabrics

ASTM D 6242-98 Standard Test Method for Mass Unit Area of Nonwoven Fabrics was used to determine the weights and the results are reported in oz/yd^2 and g/m^2. Thickness, inches and mm, were obtained by using the Measurematic Instrument with the ASTM D 5736-95. Air permeability, $ft^3/min./ft^2$, was measured on a Frazier permeability tester with ASTM D 737-96. Tensile properties were obtained according to ASTM D 5035-95. The bursting strength was measured with the ball burst apparatus on an Accutest tensile tester with the crosshead speed of 12 inches per minute, according to ASTM D 3878-89.

Polymat Equipment

The Polymat dyeing machine [Figure 3], a highly accurate tool for developing fiber dye cycles, was used to determine the effectiveness of auxiliary in the caustic extraction of water-boiled T-2 kenaf. The effectiveness of auxiliary was based on the criteria of loss in weight of fibers due to chemical extraction. The effectiveness of additional use of caustic was also determined. Using six stainless steel 750 mL beakers, six experiments were conducted simultaneously under one set of conditions, with liquor-to-fiber ratio of 8.66:1. Each of the beakers was filled with 75 g of water-boiled T-2 fiber, along with 675 g solution containing 20% * (15 g) caustic, plus 1% (0.75 g) surfactant with different auxiliaries. The beakers were then sealed to withstand pressure.

_*_/ All chemicals were taken on the basis of weight of fibers (owf)

The beakers were rotated in a heating medium of polyethylene glycol (PEG 300) to rapidly attain a temperature of 135C. The process controller PC AHIBA 100 that controlled the bath temperature was programmed for 100 minutes at 135C and subsequent rapid cooling to 60C, Figure 4. Each of the fiber samples was removed from the beaker, washed in hot water, and neutralized with 2 g/l acetic acid to obtain a fiber pH of 6.0-6.5. The fibers were dried and conditioned, and the loss in weight due to extraction was determined. The average of two sets of experiments was recorded (Table III). The fibers were test evaluated for percent elongation at break and strength, Table IV.

Groen Reactor

It had a 42-L capacity with a positively driven motor agitator to move the fiber mass and was heated indirectly with steam, Figure 5. The outer jacket of the reactor could be either heated by steam or cooled by circulating cold water. After loading/packing the T-2 fibers, the lid was secured using locking screws to withstand pressure. The reactor is almost like a conventional kier for cotton scouring that can be operated under pressure, however, with the following difference. In a cotton kier, the fiber mass is stationary and the liquid is circulated through the fiber mass (does not need an agitator). Whereas, in the Groen reactor, the fiber mass is rotated with an agitator in a stationary liquid. The agitator occupies considerable space thereby permiting less fiber mass for chemical retting. T-2 fibers (2400 g) were prewetted in water (24 L) containing 1% (owf, 24 g) surfactant and squeezed to remove air from the fibers. Air removal and wetting of the

fibers were essential for compacting and packing a large quantity of fiber in the reactor. A maximum of 2400 g of compacted prewetted fibers can be loaded in the reactor. (Maximum fiber that can be packed in the reactor was determined experimentally). A 40-L solution was used with liquor-to-fiber ratio of 16:1. The fibers were subjected to a two-step cycle of water- and caustic- extraction. Caustic retting formulation was similar to that used in polymat trials and is given in Table V. Water solubles were extracted in water containing 1% surfactant at boil (100 C), and lignin and the binding glue were extracted by caustic extraction with 20% (480 g) caustic along with 1% surfactant at boil under pressure (105 C), Figure 6. Total cycle time was 305 minutes. The reactor was filled with hot water (50C) to capacity through a hose from the port in the lid of the reactor. Care was exercised to remove air from the reactor. The air valve was closed only after air was purged out of the fiber mass in the reactor while the temperature in the reactor was reaching boil, could be at about 50-70 C. Trapped air becomes expanded at elevated temperature 70 C and escapes taking a little fluid with it. Because of indirect steam heating of the outer jacket of the reactor, it took 60 minutes to reach 100 C. Circulation at the boil was carried out for 10 minutes. Water was then drained and replaced with fresh hot water containing the formulation shown in Table V. The temperature was raised to the boil and pressure was built up to 120-127 Kpa (16-20 psi). Because of limitation in the steam supply at the SRRC plant facility, the temperature attained in the reactor was 105-110C. Circulation at boil was carried out for one hour before turning off the steam, cooling and draining the reactor. The first wash at a temperature of 90 C and above was necessary for effectively washing off caustic from the fiber. The temperature of the second hot water wash was not so critical and was about 70 C. The residual alkalinity of the fiber was neutralized with 2-4 g/l acetic acid to obtain the fiber pH of 6.0. This basically completed the chemical retting of kenaf.

The chemically retted fibers were given a special card finish. A soap solution was prepared by dissolving 36.0 g (1.5% owf) in hot water (50 C). The soap solution was added to the reactor and the fibers were finished for 10 minutes. The solution in the reactor was then acidified with glacial acetic acid (4.0 mL) and the finishing was continued for five minutes before draining the solution. The wet finished fibers were hydroextracted before drying in a forced air oven at 80 C. Dried fibers were conditioned (20 C, 65% RH) for 24 hours before carding.

T-2: Shorter Retting Cycle

We also developed a retting cycle with reduced time of water extraction at 75 C, followed by caustic extraction at 105 C with a total retting time of 263 minutes, Figure 7. Finish was applied on the retted fibers.

T-2: Determination of Effect of Varying Time of Caustic Boil

Time of caustic boil (105-110 C) was varied from 1 hour to 4 hours and loss in weight of fiber due to caustic extraction was recorded. Refined T-2 and Greige cotton 80:20 blend was carded on a cotton card. All fiber blends carded well with almost the same carding loss. A one hour caustic boil was considered optimum. Weight loss observed in carding was entirely due to loss of kenaf, and accumulated loss was the summation of losses on chemical retting and carding (Table VI).

T-2: Determination of Effect of Soap Finish

Parikh [16] has shown that soap finish improved cardability of bleached cotton fibers, so carding experiments were performed on chemically retted T-2 fibers with and without soap finish to determine if fibers could be carded more efficiently with soap finish. Carding efficiency was determined on the basis of percent weight loss of kenaf fibers in carding.

Kenaf fibers (T-2) that were water extracted and subsequently chemically retted for 1 hour were soap finished under four conditions: 0.0% finish, 0.6% finish, 1.5% finish, and 2.0% finish. The finished fibers were opened on a fiber opener/ blender and blended with greige cotton that had been opened on fiber opener/blender to obtain a 80:20 blend of kenaf:greige cotton. The 80:20 blend was passed through a fiber opener/blender before carding on a cotton card and determining the weight loss on carding. Accumulated weight loss was the summation of the losses on chemical retting and on carding, Table VII. The 80:20 carded batts were needlepunched twice to obtain 255 gsm fabric. The carding experiment was repeated twice.

E-41 Retting and Finishing

E-41 ribbon fibers were prewetted in 1% surfactant solution (without any mechanical cleaning). The fibers were extracted in hot water at 75C and retted in the formulation developed for T-2 (Table V), namely, 20% caustic + 1% surfactant + 0.2% anthraquinone followed by only one hot water wash at 90 C before finishing with 1.5% soap, Figure 8. The fiber weight loss due to this cycle of retting was 23.8%. Preparation cycle was shorter than that of T-2. Fibers were a lustrous gold color, and were easy to handle on card and needlepunching.

For the fiber webs to be made on an air-laid system, the E-41 fibers need to be softened only and need not be caustic retted. These requirements were met by extracting E-41 ribbons for 1 hour in water containing 1% surfactant at boil, Figure 9. The retted fibers were finished with 2.0% soap. The weight loss due to water extraction was 8%. Most of the bark was removed, some of it still remained, yet the air-laid composite webs (35:35:30) were needlepunched without breaking needles.

Fiber Properties

Fiber physical properties such as the bundle breaking tenacity and elongation were tested with stelometer (ASTM D-1445-75). We performed ten replicas for each of the stages of fiber cleaning and chemical retting of T-2 fibers treated in Polymat. The average of these readings along with standard deviations is reported in Table IV.

Preformed Composites

Composite felts containing PP can be thermoset to a permanent shape when heated in a suitable tool. The PP acts as a thermal component that easily molds at elevated temperatures. When the tools are set at the correct temperature and the correct procedures are followed, automotive parts can be made that have excellent shape stability and acoustical properties combined with the thermal insulation and an even, soft, resilient surface of locally formed areas. Pressformed composites can also have decorative facing material laminated to the face and can be used as car roof liners, parcel shelves, and wall panels. Compressed composites are often used for sound absorption. The composites of the present study were improved because of the fibrous structure of kenaf. Flow charts for producing needlepunched fabrics are shown in Figure 10.

Results and Discussion

Fiber Analysis

The percentages of fiber, core, bark, and dust in T-2 and E-41 kenaf samples are shown in Table II. It may be noted that the core was readily discernible from fiber and bark and that the trash, which was primarily kenaf dust, was negligible for E-41 and was 4% for T-2. The T-2 fibers were short and had high percentage of bark clinging to the fibers.

Since T-2 consisted of 22% bark and 9% core material, it obviously required a longer route for cleaning and chemical retting than E-41, which contained only 10% bark and 3% core. Furthermore, since the T-2 fibers were mechanically cleaned by passage through a Rando cleaner, the fiber weight loss was high, at 40%. The fiber loss was so high because not only were the bark and core fibers removed, but also the good bast fiber. The resulting fiber was free from all of the core fibers and most of the bark. The E-41 fibers were sufficiently clean, did not require mechanical cleaning, and were taken for chemical retting without any mechanical cleaning.

Polymat: Chemical Retting of T-2 and the Effect of Additives

An 8% fiber loss was observed when the mechanically cleaned T-2 fiber was boiled in water with 1% surfactant in the Groen reactor. Table III shows the effect of additives in a solution of 20% caustic with 1% surfactant on the chemical retting at 135 C of water-boiled T-2.

With weight loss as the criteria, anthraquinone was found to be an efficient chemical additive for retting the fiber. Even at a low concentration of 0.1%, the weight loss was increased by nearly 2% compared to that obtained with the control caustic solution. Sodium bisulphite was not found to be as efficient. Thus, it was concluded that 0.2% anhtraquinone with 20% caustic and 1% surfactant would be an ideal retting formulation for the scale up trials in the Groen reactor. Further scale-up trials used only 20% caustic although the loss in fiber weight was slightly higher with higher concentrations of caustic (34.72% and 38.33% with 30% and 50% caustic solutions respectively).

Polymat: T-2 Fiber Strength and % Breaking Elongation

Raw fiber had a relatively high 6.33% elongation at break. This was probably due to the wax on the fiber, Table IV. The test data indicate that the fiber strength had remained intact and that there was no fiber damage due to caustic retting. Fiber breaking strength and elongation did not change significantly after the mechanical cleaning, water extraction and chemical retting treatments. Standard deviations of the data indicate that the kenaf fibers exhibited moderate variations in strength and elongation.

T-2: Chemical Retting and Finishing

Essential features of good chemical retting and finishing of kenaf, as revealed by the various experiments conducted, are enumerated in Table VIII. Compared to the earlier work [10], we significantly improved the preparation of kenaf by using a powerful alkali-stable surfactant in the prewetting and in the caustic retting formulation. Only through prewetting and the removal of air from the fibers was the compacting of fibers possible. This in turn helped in lowering the liquor-to-fiber ratio in the reactor to 16:1 vs 75:1 in the earlier work [10]. With the inclusion of the surfactant and a catalyst in the caustic retting formulation, we were able to use 0.12N (480 g) caustic for retting 2400 g fibers, compared to 2N to 3N solutions in the earlier work. The use of a card finish certainly aided the carding.

Because of limitations in the steam supply, heat ramping was slow and took longer to reach 105C. This cycle time would be considerably shorter in an industrial environment where hot water at 90C and the required steam supply are plentiful. The weight loss in one hour of caustic retting of water-boiled T-2 was 21%. Thus, refined fibers were found acceptable for carding through a cotton carding system. The T-2 fibers refined by a shorter cycle, Figure 7 (reduced water extraction), were equally as good for processing on the cotton card.

Initial developmental trials were made with the one hour-, two hour-, and four hour- caustic boil while keeping the rest of the stages unaltered. The four-hour caustic boil caused a higher weight loss of 32%. In the previous work at SRRC, researchers expected that the fiber refining had to be carried out to almost complete delignification with weight loss of 41%, in order for the fibers to be successful carded on a cotton carding system. In the present work, the 21% weight loss (i.e., partial delignification) was shown to be adequate. This level of lignin extraction is easily achieved by the proposed cycle, which is even amenable to scale-up to commercial scale. Unfortunately, the previous researchers did not report percent loss of fiber on carding. Based on our present research, we observed that T-2 short fibers, had a quite high total accumulated loss of 45.9%, including the loss in carding (Table VI).

E-41: Chemical Retting and Finishing

Compared to T-2 fibers, the refining cycles forE-41 fibers were far simpler. The E-41 fibers neither required mechanical cleaning nor needed a long caustic wash off. Fiber waste losses were low, (Table IX), and the retting produced a lustrous fiber. However, the loss of fiber in carding was in the same range as that of the T-2 fibers. For example, the 50:50 blend of chopped E-41with PP (to produce 600 g nonwoven fabric) showed a fiber loss in carding in the range of 21%- 24%. We have found carding losses in the same range of 20-25% as for carding jute, flax and other vegetable fibers.

Evaluating Nonwovens

Physical properties of the nonwoven fabrics are shown in Tables X and XI. The longer the caustic boil, the greater is the refining of the fiber and the greater is the packing of the fibers in the making of the nonwoven fabrics, resulting in lower air permeability. Textile properties of kenaf composites are comparable with those of Jute. Carded webs were generally needlepunched four times to get compacted nonwovens. However, needlepunching only twice keeps the fabric sufficiently lofted with significantly high air permeablity, (see D-2 vs. the C-20 samples for jute). Cotton fines being fine fibers, much finer than jute and flax, many more fibers are required to produce a given weight composite, (for example, 20 0z per square yard) as compared to kenaf and jute composites, resulting in lower air permeability. C20-3 cotton composite had an air permeability of 38.3 vs. 91.0 for C20-2 jute composite and 89.9 for C20-1b kenaf composite.

Conclusions

Modified chemical retting procedures have been developed for two distinctly different varieties of kenaf, namely, Forage harvested short T-2 fibers and naturally retted long E-41 fibers. The procedures deliver fibers of acceptable and reproducible quality. For kenaf to become a value-added crop for use in nonwovens, considerations must be given to harvesting of the plants while they are green and producing decorticated fiber ribbons for chemical retting. The chemical retting cycle of E-41 kenaf ribbons can be much shorter than that of the T-2 fibers. Also, the quality of E-41 fibers thus produced is suitable for processing through a cotton card. Not only is fiber-waste loss in chemical retting decreased, but also the fiber quality is superior in luster, brittleness and flexibility. However, for fibers to be suitable for processing on a card, they need to be refined via caustic retting. For processing on an air-laid system, the fibers may be refined to a lesser extent. Hot water extraction without caustic retting and finishing with a card finish produces fibers that are suitable for air-laid and needlepunching. In general, long fibers are found suitable for use in nonwovens. Mechanically harvested short fibers should be best utilized in the pulp and paper industry.

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Table I. Data* from Tao et. al. [9].

Concentration, N (Total caustic used, g)	Reaction time, Hrs	Final weight of fiber, g (% loss in weight)
1 N (1200 g)	1	289 (27.75%)
1 N (1200 g)	2	266 (33.50%)
1 N (1200 g)	3	260 (35.00%)
2 N (2400 g)	3	240 (40.00%)
3 N (3600 g)	3	235 (41.25%)
4 N (4800 g)	3	235 (41.25%)

*_/ 400 g of fibers were treated in each of the following experiments in Groen reactor using 30 L solution. Caustic concentration and the time of the reaction at 110C were varied. Final weight of the fiber and % loss in weight of the fiber are shown in the last column. Liquor-to-Fiber ratio was 75:1.

Table II. Analysis of Kenaf Supply.

Fiber Variety	Fiber, %	Core, %	Bark, %	Trash Dust,%	Total waste,%
T-2	65	9	22	4	35
E-41	87	3	10	Nil	13

Table III. Retting of water-boiled T-2 in Polymat and the effect of Additives in solution of 20% caustic + 1% surfactant

Sample #	Auxiliary, or chemical	Wt. Loss, %
1	NIL	30.33
2	0.1% Anthraquinone	32.12
3	0.2% Anthraquinone	32.15
4	1.0%Sodium Bisulphite	31.10
5	10.0% Caustic*	34.72
6	30.0% Caustic**	38.33

*/ This solution contained 30% (20% + 10%) caustic + 1% surfactant
**/ It contained 50% caustic (20% + 30%) + 1% surfactant

Table IV. T-2 Fiber strength and % elongation at break.

	Elongation at Break, %		Strength, g/Tex	
Sample Detail	Average	Std Deviation	Average	Std Deviation
Raw Fiber	6.33	2.2	23.6	3.1
SRRC Cleaned	1.61	1.1	21.3	4.8
Water Extracted	1.76	1.4	20.5	4.3
Retted with 20% caustic	1.54	0.8	19.6	2.0
Retted with 50% caustic	1.68	1.0	20.8	3.2

Table V. Groen Rector Formulation.

CHEMICAL	% owf
Caustic Soda	20.0
Strodex V8	1.0
Anthraquinone	0.2

Table VI. Effect of Time of Caustic Boil on Fiber Weight Loss on Water-boiled T-2.

Time of Caustic Boil	Caustic Retting weight loss,%	Weight loss due to water + caustic retting,%	Carding weight loss, %	Accumulated weight loss,% (water- caustic-retting and carding.)
1 Hour	21.0	27.32	26.25	45.85
2 Hour	27.0	32.85	26.00	52.38
4 Hour	32.0	37.44	26.00	55.73

_*/ Water extraction caused 8% fiber loss

Table VII. Optimizing Soap Finish.

Soap Finish % on T-2 Kenaf Fibers	Carding Weight Loss, %	Accumulated Weight Loss, %
0.6%	27.50%	42.70%
1.5%	26.25%	41.73%
2.0%	26.50%	41.90%
0.0%	37.50%	50.62%

Table VIII: Features of the Development.

Prewetting Fibers.	Prewetting in a surfactant solution helps in air removal and thereby compacting the fibers.
Low liquor-to-fiber ratio.	Maximum fiber loading in the reactor can only be done with compacted wet fibers. In the Groen reactor, agitator occupied a significant space, even then liquor-to-fiber ratio attained was 16:1. Had we used a conventional cotton kier we would have achieved still lower ratio (5:1). Low liquor-to-fiber ratio means high productivity.
Air Removal in caustic retting.	Air has to be purged out before caustic retting the fibers under pressure. Air would degrade the causticized hot fibers.
Water Extraction	It removes the water solubles and dust and thereby makes caustic retting an efficient process.
Anthraquinone as catalyst	0.2% concentration improves the efficiency of the caustic retting process.
Thorough caustic wash off and neutralizing	Wash at 90C and at 70C followed by weak acetic acid accomplishes the fiber pH of about 6.0
Finishing with 0.6% to 1.5% soap	Finishing fibers aids carding. It helps in reducing the alkali concentration in caustic retting.
Finishing	Finishing can be done either in the reactor or outside the reactor. By finishing fibers outside the reactor, we increase the productivity of the reactor as the cycle time decreases.

Table IX. E-41: Fiber Weight Loss on Retting.

Treatment	Fiber weight loss, %
Boiled 1Hr. in water containing 1% surfactant, Refer Figure 9.	10
Boiled 1 Hr. in 5% caustic + 1% surfactant + 0.2% anhtraquinone	14
Water Extracted at 75C and boiled 1 Hr. in 20% caustic + 1% surfactant + 0.2 % anthraquinone, refer Figure 8.	25

Table X. Nonwovens Textile Properties: T-2 kenaf (caustic boiled and finished) 80/20 T-2/Greige cotton, carded, needlepunched twice.

Details	Weight Oz/yd^2 (g/m^2)	Thickness Inches (mm)	Air Permeability ft^3/min/ ft^2	Tensile Strength lb$_f$ MD	Tensile Strength lb$_f$ CD	Elongation % MD	Elongation % CD
B-1 1 hour boil	7.5 (255)	0.150 (3.81)	391.0	0.639	0.148	48.4	96.5
B-2 2 hour boil	7.7 (262)	0.184 (4.67)	384.8	0.540	0.194	38.3	74.2
B-3 4 hour boil	8.5 (290)	0.187 (4.75)	240.2	0.787	0.277	31.0	45.3
B-4 1 hour boil E-41 (finished)	7.3 (249)	0.163 (4.14)	411.6	0.345	0.088	39.5	36.8
B-5 1 hour boil (unfinished control)	7.5 (255)	0.183 (4.65)	272.0	0.687	0.203	34.4	54.9

Table XI. Nonwovens Textile Properties: Carded, Needlepunched 4 times, 35/35/30 vegetable fiber/recycled polyester/propylene on Freudenberg PET scrim.

Details	Weight Oz/yd^2 (g/m^2)	Thickness Inches (mm)	Air Permeability ft^3/min/ft^2	Bursting Strength Ball Burst (lb$_f$)
Approximately. 20 0z/yd^2				
C20-1a E-41 kenaf composite	20.0 (679)	0.315 (8.00)	84.4	223.5
C20-1b E-41 kenaf composite	20.6 (700)	0.315 (8.00)	89.9	385.1
C20-2 *Jute composite*	20.0 (679)	0.310 (7.87)	91.0	389.8
C20-3 *Cotton fines composite*	21.8 (740)	0.300 (7.62)	38.3	434.6
C20-4 *70/30 recycled polyester/polypr pylene*	21.7 (736)	0.350 (8.89)	82.6	418.4
D-2 *Jute 50/50 veg. fiber/PP Carded, needlepunched twice*	21.5 (728)	0.430 (10.92)	604.4	204.9
Approximately 30 oz/yd^2				
C30-1 Kenaf (E-41)	31.3 (1063)	0.455 (11.56)	67.2	288.1
C30-2 Jute composite	30.0 (1018)	0.428 (10.87)	68.6	391.5
C30-3 Cotton fines	30.0 (1018)	0.390 (9.91)	29.7	517.4
C30-4 Hemp composite	30.0 (1018)	0.400 (10.16)	41.2	428.4
C30-5 70/30 recycled PET/PP	29.8 (1013)	0.450 (11.43)	57.0	420.0

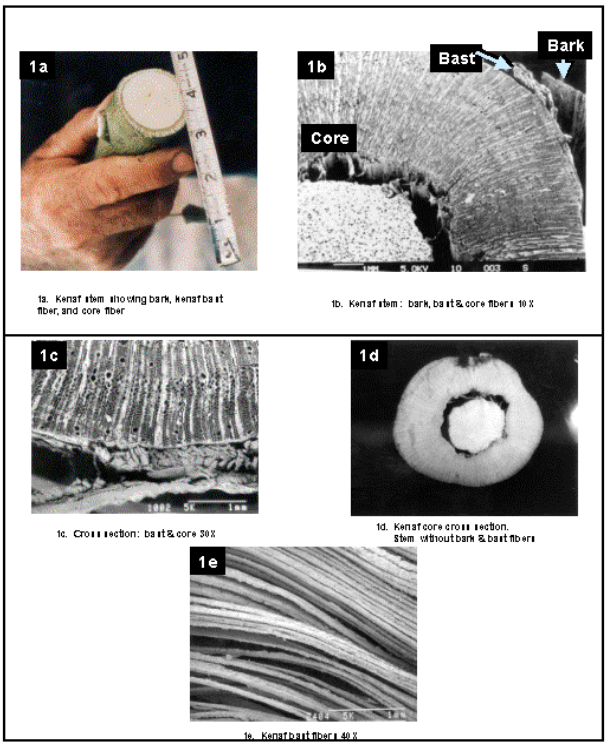
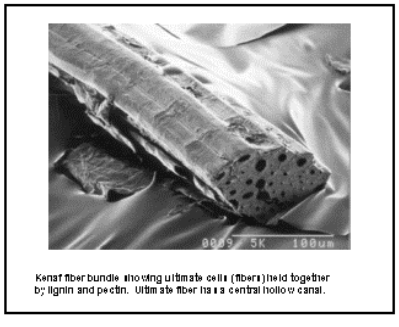


Figure 1.



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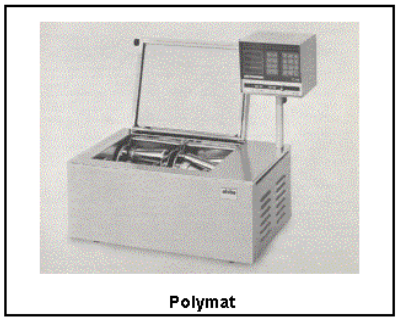

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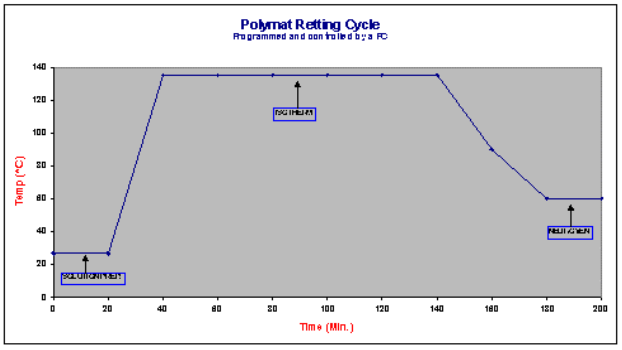

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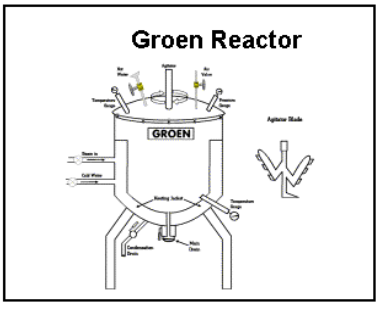

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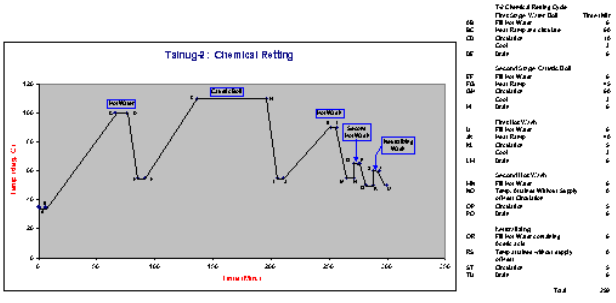

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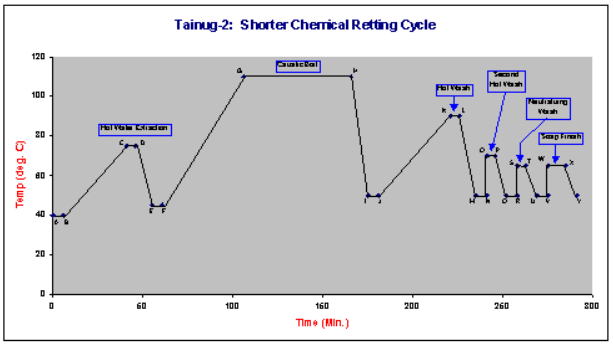

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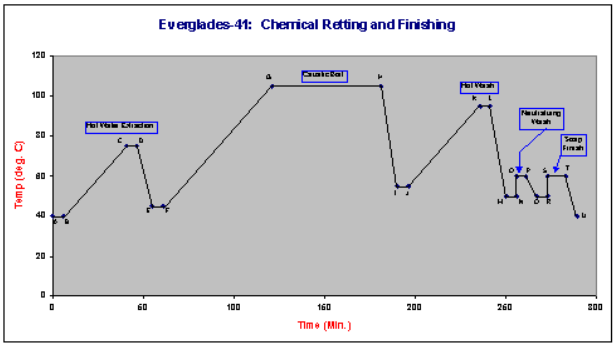

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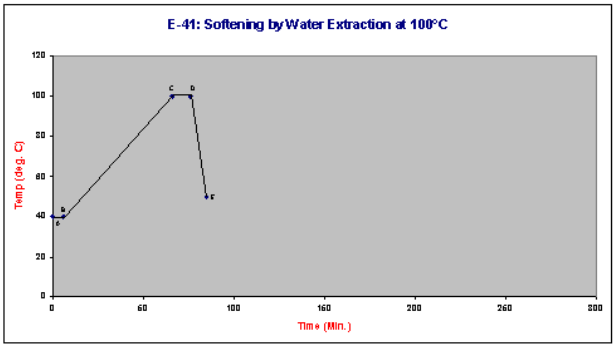

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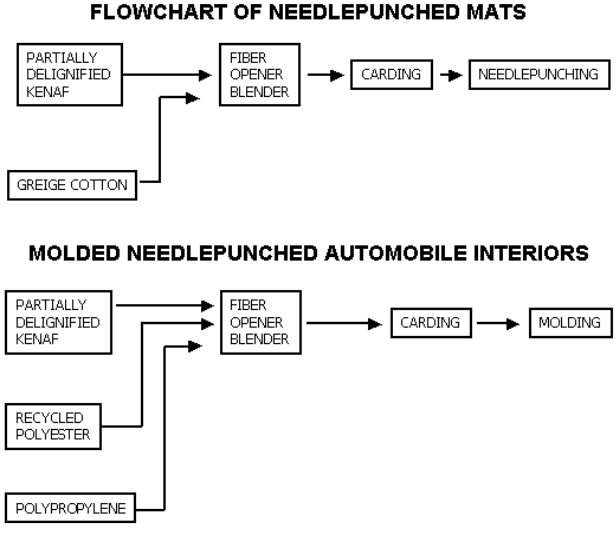

Figure 10.