Properties of nonwoven mats from kenaf fiber

Weiying Tao, Jerry P. Moreau, and Timothy A. Calamari

ABSTRACT: Raw kenaf fiber consists of coarse bundles of ultimate cells (fibers) held together by lignin and pectins. These fibers must be refined for easier refining through nonwoven equipment. Kenaf was treated with sodium hydroxide to partially extract lignin and separate the fiber bundles. The concentration and duration of sodium hydroxide treatment were varied to determine optimum conditions. Treated kenaf fibers were opened, carded, and then needlepunched into sturdy nonwoven mats containing 100% kenaf or kenaf/cotton blends. Blended mats of kenaf/cotton retained more oil than mats prepared from polypropylene fibers. Other potential applications for these biodegradable mats include prevention of soil erosion, weed control, and the cleanup of waste liquids.

KEYWORDS: Batts, carding, cotton, end use, fiber mats, fibers, kenaf, lignins, mixtures, needling, nonwovens, polypropylene, processing, properties, sodium hydroxide.

The kenaf plant, *Hibiscus cannabinus* L., is a tropical crop native to Africa. It is a new commercial crop in the United States, where it is grown mostly in the south and west *(1)*.

Kenaf is an annual plant with a single, straight, unbranched stem consisting of an outer fibrous bark and an inner woody core. The kenaf stem grows to 5–6 m in length and 25–35 mm in diameter over a period of 5–6 months, at which time it is harvested.

Raw kenaf fiber, obtained from the outer bark, is actually a bundle of fibers. It consists of lignocellulosic fiber bundles that offer the advantages of being inexpensive, biodegradable, and environmentally safe. The fibers have been traditionally used to produce cordage and coarse yarns, canvas, and sacking *(2)*. Kenaf has also been used on a limited scale as a substitute for wood in the production of pulp and paper in Thailand and the People's Republic of China *(3)*. However, it has not reached full-scale commercial success in the United States, despite USDA findings in the 1960s and 1970s demonstrating its economic value and quality in paper applications *(3, 4)*.

Recent research has identified other uses for kenaf, such as ground-covering materials, filters, and oil absorbents *(4)*. However, because of the coarseness and stiffness of the fiber bundles, processing of kenaf remains a problem. These unfavorable properties also have inhibited the development of higher-quality nonwovens containing kenaf. Natural retting is a simple and inexpensive process commonly used to separate bark fibers and reduce the size of fiber bundles for use in textile processing. However, natural retting causes environmental problems. Therefore, other methods must be developed to refine the fiber.

Kenaf contains approximately 65.7% cellulose, 21.6% lignin, and pectins *(5)*. As shown in **Fig. 1**, a kenaf bark fiber comprises a bundle of ultimate cells. Each cell has a polygonal shape with a central hole, or lumen. The cells overlap along the length of fiber. The ultimate fiber cells, which constitute 35–40% by weight of the stem, are only 3–4 mm in length. The ultimate cells of the core fiber, 60–65% by weight of the stem, are even shorter than those of bark fibers, typically 0.5–0.7 mm *(3,*

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6). Therefore, the bark fibers are preferred for textile applications.

Natural lignin, which plays an important role in the structure of all woody plants, helps hold kenaf fiber bundles together. In the papermaking industry, lignin is removed from wood by various commercial pulping processes such as alkali pulping *(7)*. Alkali also has been used to remove lignin from kenaf for papermaking *(3, 6)* and for nonwoven processing *(8)*. In this study, sodium hydroxide was used to refine the fibers by partially extracting the lignin. The more lignin that is extracted, the finer the fiber bundles. Appropriate control of the lignin remaining in the kenaf fiber bundles determines the suitability for nonwoven processing.

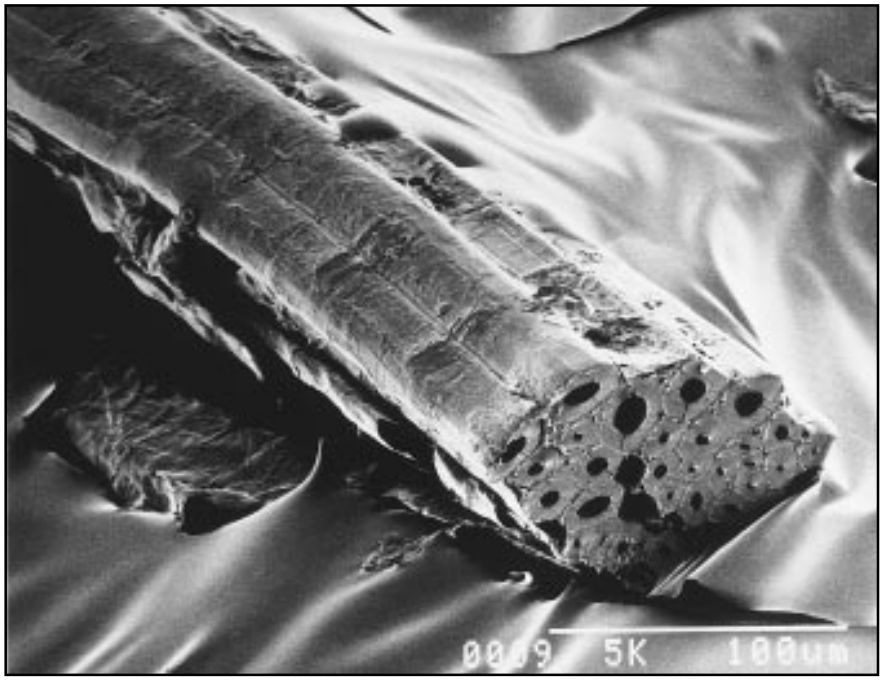
One objective of this study was to chemically refine kenaf fiber so that it would be acceptable for processing into batts from a carding machine. In our previous research, mechanically separated raw kenaf fiber bundles were processed into kenaf batts on an air-laid webber (Rando) *(9)*. Mats of 100% kenaf could not be successfully needlepunched because air-laid kenaf batts were not very sturdy and thus difficult to handle. Rayon scrims were placed above and below the kenaf batt to provide a stable structure for the subsequent needlepunch process. Essentially, the strength of the mats was attributed to the addition of rayon.

Carded kenaf batts are expected to provide better structural integrity than those obtained from the air-laid process of batt formation. The second objective of the present study, therefore, was to prepare carded batts. The third objective was to process the batts into nonwoven mats on a needle loom and then measure the properties of these mats.

This report presents the results of laboratory experiments to

- Optimize chemical refinement of kenaf fiber bundles for use in production of nonwoven mats
- Evaluate the physical properties of kenaf nonwoven mats for potential application as biodegradable ground covers and for cleanup of waste liquids and oil.

1. View of a kenaf fiber bundle showing ultimate cells (fibers) held together by cementing material



I. Sodium hydroxide treatment conditions [a]

Concentration, N	*Reaction time, h*
1	1,2,3,4
2	3
3	3
4	3

[a] Temperature, 110°C; solution volume, 30 L; pressure, 127 kPa

II. Result of sodium hydroxide treatment [a]

Concentration, N	*Reaction time, h*	*Final weight, [b] g*
1	1	289
1	2	266
1	3	260
1	4	261
2	3	240
3	3	235
4	3	235

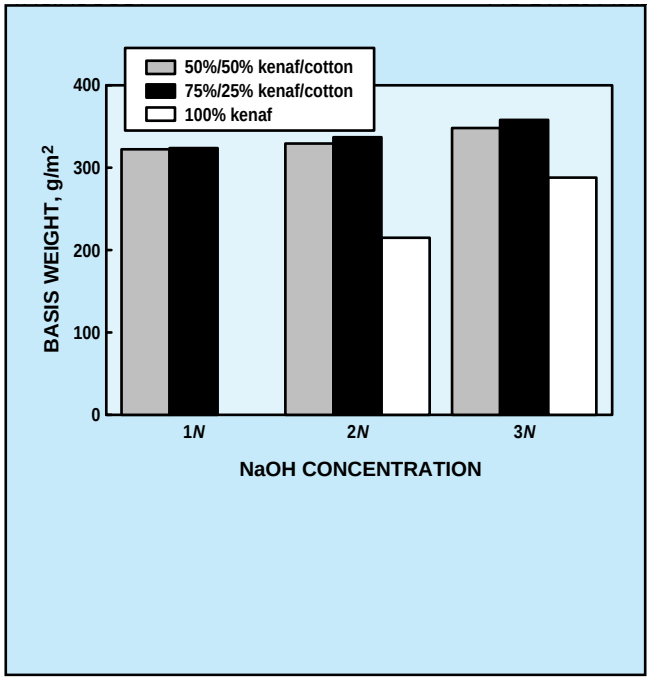
[a] Temperature, 110°C; solution volume, 30 L; pressure, 127 kPa
[b] Initial weight of all samples before treatment was 400 g

Experimental

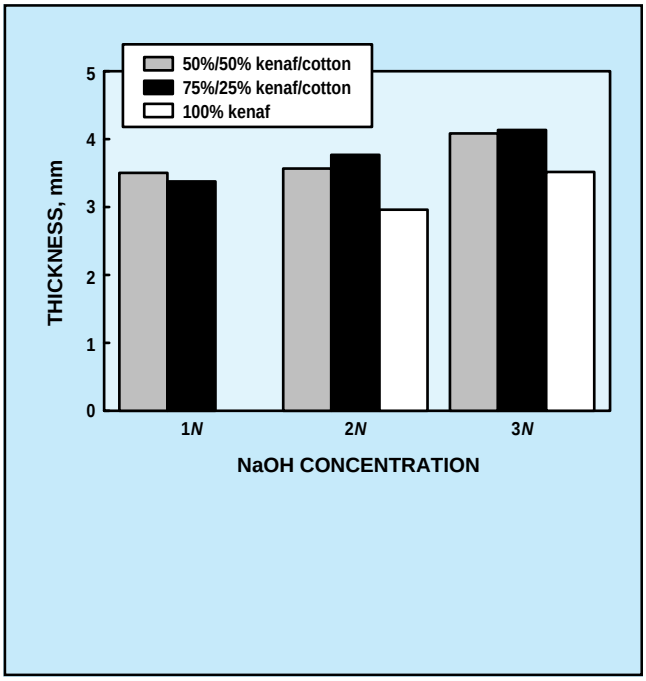
Materials, treatment, and mat formation

Raw kenaf fiber bundles (AGRO-Fibers, Inc.) were used as the starting untreated material. The raw fibers were mechanically processed

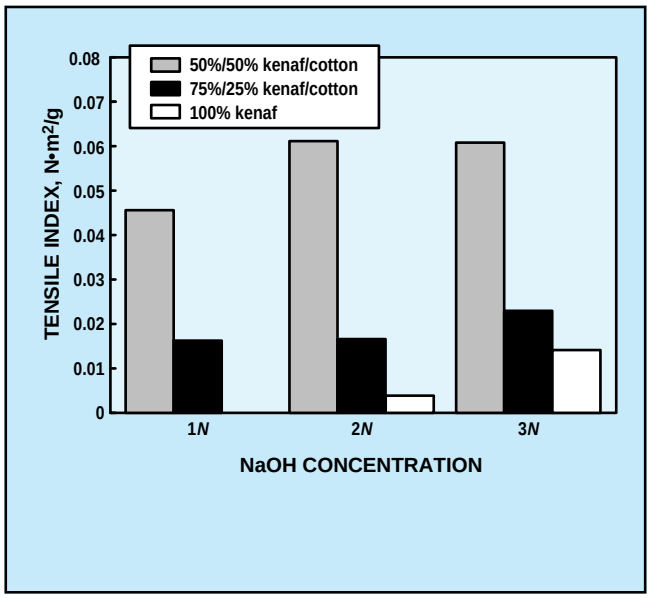
2. Basis weight of kenaf mats



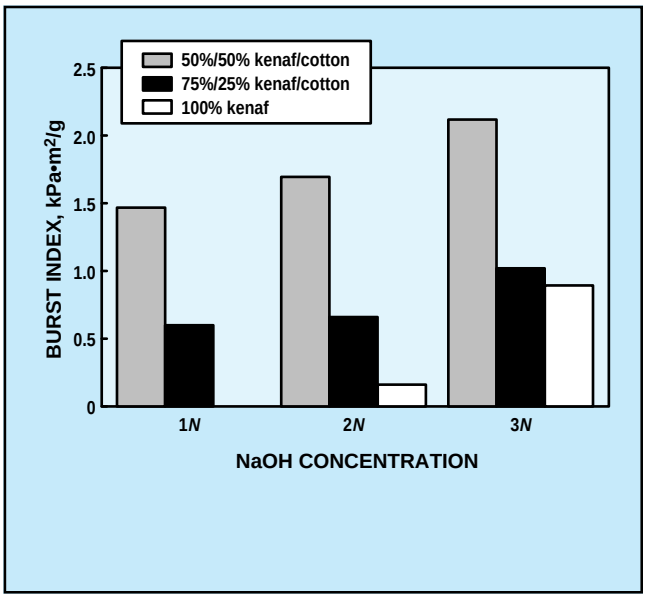
3. Thickness of kenaf mats



4. Tensile index of kenaf mats



5. Burst index of kenaf mats

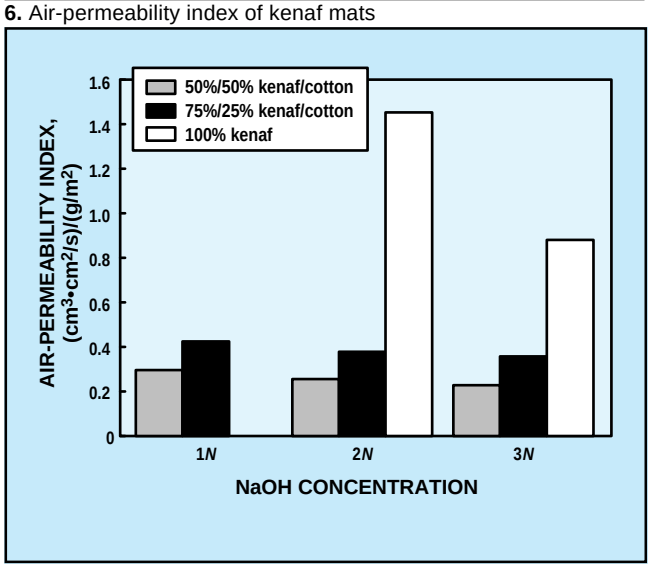


through a cleaner to remove core material. The cleaner (Rando) is a roller-type cleaner equipped with fine saw-tooth wires. The fiber bundles were approximately 6–12 cm in length and 0.5–3 mm in diameter.

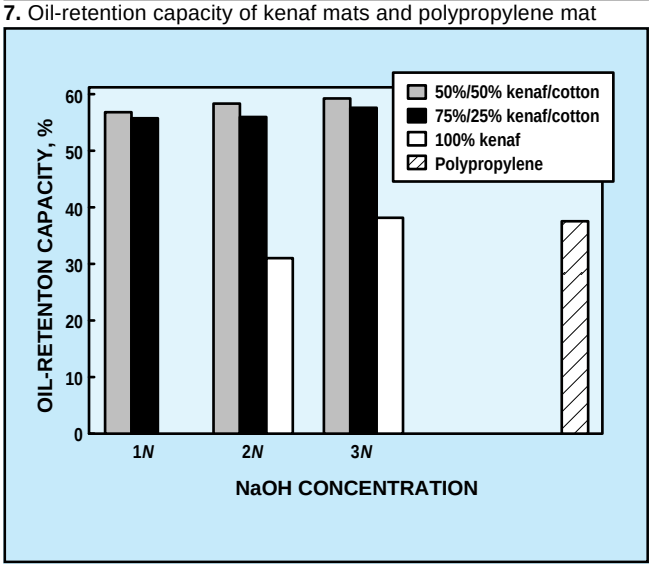
A 40-L steam reactor (Groen) with an agitator running at 54 rpm was used for alkali treatment. The reactor was run at a pressure of 127 kPa using 30 L of sodium hydroxide solution. Temperature was kept at 110°C because of the limitation of the steam supply. Sodium hydroxide concentration and duration of treatment were varied in an effort to determine optimum conditions, as seen in **Table I**. After treatment, the fibers were washed with water and then air dried. The dried kenaf fibers and gray cotton fibers were opened separately or blended on an opener (SpinLab) with a constant feed-roll speed before carding.

Batts were successfully prepared using 100% kenaf fibers and blends of kenaf/cotton using a card (Whitin)

6. Air-permeability index of kenaf mats



7. Oil-retention capacity of kenaf mats and polypropylene mat



equipped with plates (Cardmaster). The doffer-roll speed was approximately 11.3 rpm, and the cylinder speed was approximately 198 rpm. The batts were then needlepunched twice on a needle loom (Morrison Berkshire) equipped with a single 31.8-cm board containing 575 needles. The needle design was l5 x 18 x 40 x 3.5 (F222-G92919, Groz–Beckert). Batts were processed into nonwoven mats at a linear speed of 1.83 m/min, 23 penetrations/cm^2, and 228 strokes/min.

Mat evaluation

The nonwoven mats were evaluated for weight, thickness, tensile strength, bursting strength, air permeability, and oil absorption. Fabric thickness was measured with a gauge (Randall & Stickney) at 35.8 g/cm^2 pressure *(10)*. Fabric weight was determined from six specimens, each 2.54 cm x 17.78 cm, cut in the machine direction. ASTM test methods *(11)* were used to determine tensile strength (ASTM D 1682-64), bursting strength (ASTM D 3786-87), and air permeability (ASTM D 737-75).

A modified method to determine water retention *(12)* was adopted to determine the oil-retention capacity of the kenaf mats. Duplicate 7-cm-diam. samples of the nonwoven mats were weighed and then completely submerged in paraffin oil (Saybolt viscosity 345–355 s at 38°C) for 10 min, allowed to drip for 10 min, and then reweighed to determine the soak weight. Samples were then blotted between five absorbent paper towels with a 600-g weight for 3 min and reweighed to determine the blotted weight. The oil-retention value was calculated from the following equation:

$$\text{Oil retention, \%} = [(\text{blotted wt.} - \text{original wt.})/(\text{soak wt.} - \text{original wt.})] \times 100$$

Results and discussion

Sodium hydroxide treatment

Results of treatment of raw kenaf fiber bundles with NaOH are shown in **Table II**. The treatment also removed the small amount of dust contained in the raw kenaf. Since the original fiber weight was 400 g before each treatment, the lower fiber weight after treatment indicates greater lignin removal, which produces a finer fiber. For 1*N* concentration, results showed that optimum reaction time occurred after 3 h of treatment, with the final weight decreasing from 289 g to 260 g. Treatment for 4 h did not produce an additional decrease in weight, nor did it improve fiber fineness as determined by visual inspection and feel. Methods for accurately measuring the fineness of kenaf fibers are being investigated.

The 3-h NaOH treatment was thus selected for determination of the effect of caustic concentration on weight loss. Increasing the concentration from 1*N* to 2*N* resulted in a noticeable decrease in weight, from 260 g to 240 g. The weight dropped only slightly when the concentration was increased to 3*N*, from 240 g to 235 g. Treatment with 4*N* NaOH gave the same results as 3*N*. Thus it was concluded that a 2*N*, 3-h treatment was most suitable.

Kenaf mats and properties

Fiber bundles of 100% kenaf treated with 2*N* and 3*N* NaOH solutions for 3 h were successfully carded to provide batts with good structural integrity. Kenaf fiber treated with 1*N* NaOH for 3 h was still too coarse for batt formation of 100% kenaf on the card. Therefore, only mats of kenaf/cotton blends could be prepared at this level of NaOH treatment. Blending cotton into the kenaf helped carry the kenaf through the card.

Batts were subsequently needlepunched into nonwoven mats containing 100% kenaf, 75%/25% kenaf/cotton blends, and 50%/50% kenaf/

cotton blends. Attempts at carding raw (untreated) kenaf fiber were ineffectual because of the coarseness of the fiber bundles. The raw kenaf fiber was discharged from the card as trash instead of being recovered from the doffer roll. Refinement of the fiber by NaOH treatment was essential for successful carding.

Physical properties of the kenaf nonwoven mats are shown in **Figs. 2–6**. Weight and thickness dimensions are shown in Figs. 2 and 3, respectively. Strength and air-permeability data (Figs. 4–6) are normalized for variations in mat weight. Tensile index and burst index increased with increasing NaOH concentration, as seen in Figs. 4 and 5, respectively. This was probably due to better cohesion of the large number of finer fibers. Within the respective NaOH concentrations, strength increased as the percentage of cotton increased. The greater strength of the mats blended with cotton was attributed to the better cohesion and entanglement of the cotton fibers.

The air permeability of the nonwoven mats decreased with increasing NaOH concentration, as seen in Fig. 6. This is because the finer fibers obtained at higher NaOH concentrations allowed for greater compaction during needlepunching, resulting in lower air permeability. The air permeability increased as the percentage of kenaf in the mat increased. This would be expected, since kenaf fibers are coarser than cotton fibers and thus would have higher air permeability. Nonwoven kenaf mats with different properties can be produced by altering the treatment conditions and the kenaf ratio in the mats.

Kenaf mats as oil sorbents

The potential for using kenaf fiber mats as an oil sorbent were investigated by measuring their oil-retention capacity and comparing the results with mats produced from polypropylene fiber. (Polypropylene fiber is the most commonly used material in commercial oil-absorbing products.) Replacement of a synthetic material with a natural material offers the advantage of biodegradability. The polypropylene mats were prepared using the same method that was used to produce the kenaf mats.

Figure 7 shows that oil retention for a 100% kenaf mat was comparable with that of a polypropylene mat. The mats containing kenaf/cotton blends retained more oil than the polypropylene mats. For mats containing blended fibers, oil retention increased slightly with increasing NaOH concentration of kenaf treatment.

The percent oil retention in the mat increased as the blend ratio of cotton increased. This was attributed to the hydrophobic surface characteristics of gray cotton fiber, which still contained natural waxes *(13)*. These results indicated that mats prepared from biodegradable natural material had better oil-retention properties than the mat prepared from polypropylene fiber.

Summary

Treatment of raw kenaf fiber with sodium hydroxide reduced kenaf fiber bundle size and improved processability. Fine kenaf fibers can be obtained by treatment with 2*N* NaOH for 3 h. The treated 100% kenaf fiber bundles and kenaf/cotton blends were successfully carded and needlepunched into nonwoven mats with good structure.

Mat strength increased with an increase in (a) the concentration of NaOH treatment and (b) the blend ratio of cotton fiber. Air permeability increased with an increase in the blend ratio of kenaf fiber and decreased with an increase in the concentration of NaOH treatment.

Oil retention of a nonwoven mat produced from 100% kenaf was comparable with that of a mat produced from 100% polypropylene fiber. Oil retention of mats from kenaf/cotton blends was greater than that of mats from both 100% kenaf and 100% polypropylene. These biodegradable kenaf nonwoven mats have potential application in prevention of soil erosion, weed control, and cleanup of waste liquids.

Literature cited

1. "Industrial uses of agricultural materials, situation and outlook report," United States Department of Agriculture, Economic and Research Service, Washington, DC, June 1993.
2. Cook, J. G., *Handbook of Textile Fibers*, Merrow Publishing, Watford, UK, 1960, p. 20.
3. Kaldor, A. F., Karlgren, C., and Verwest, H., *Tappi J.* 73(11): 205(1990).
4. Werber, F. X., "Kenaf product and process research in ARS," *1993 International Kenaf Conference Proceedings*, International Kenaf Assoc., Ladonia, TX.
5. *Encyclopedia of Textiles, Fibers, and Nonwoven Fabrics* (M. Grayson, Ed.), John Wiley & Sons, New York, 1984, p. 175.
6. Kaldor, A. F., *Tappi J.* 72(9): 137(1989).
7. Stamm, A. J., *Wood and Cellulose Science*, Ronald Press, New York, 1964, pp. 122–31.
8. de Guzman, Z. I., Berana, N. B., and Reyes, A. M. Jr., *NSTA Technol. J.* Jan.–Mar.: 77(1982).
9. Moreau, J. P., Bel-Berger, P., and Tao, W., *Tappi J.* 78(2): 96(1995).
10. *U.S. Federal Supply Service, Textile Test Methods*, Method 5030, Federal Test Methods Standard No. 191A, General Services Administration, Washington, DC. 1978.
11. *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, 1988.
12. Moreau, J. P., Bruno, J. S., and Vigo, T. L., *INDA J. Nonwovens Res.* 5(1): 27(1993).
13. Choi, H-M., Kwon, H. J., and Moreau, J. P., *Textile Res. J.* 63(4): 211(1993).

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