# KAPOK I: CHARACTERISTCS OF KAPOK FIBER AS A POTENTIAL PULP SOURCE FOR PAPERMAKING

Somporn Chaiarrekij,* Apiporn Apirakchaiskul, Kuntinee Suvarnakich, and Suda Kiatkamjornwong

The potential use of kapok fiber for pulping and papermaking has been investigated. The kapok fibers were cooked using the optimal dosage of sodium hydroxide determined from the experiments. Then, the pulp was refined with two passes using a disc refiner and mixed with commercial hardwood pulp and/or softwood pulp at different blend ratios to make papers. It was found that addition of the kapok pulp to the mixed pulps improved the tensile and burst strengths of the sheets but decreased the tear resistance and elongation. Water repellency of the sheets prepared from the kapok pulp mixed with the commercial pulps was also improved. These results indicate that kapok fiber can be a quality pulp source for papermaking, especially for packaging paper requiring strength and water repellency.

*Keywords: Kapok fiber; Properties; Raw material; Papermaking*

*Contact information: Department of Imaging and Printing Technology, Faculty of Science, Chulalongkorn University, Phayathai Road, Bangkok, 10330 Thailand; * Corresponding author: Huaja@hotmail.com*

## INTRODUCTION

The kapok tree, *Ceiba pentandra (L.)* Gaertn. (Malvales: Malvaceae), formerly Bombacaceae family, is cultivated widely in Southeast Asia, as well as other parts of East Asia and Africa. The kapok fiber is an agricultural product obtained from the fruits of the kapok tree (Tang et al. 2008; Qiuling and Lin 2009). Kapok fibers have a hollow structure with a thin fiber wall and large lumen (Xiao et al. 2005; Lim and Huang 2007). The diameter including the fiber wall is 16.5 ± 2.4 μm. The lumen diameter is 14.5 ± 2.4 μm and the fiber length is 25 ± 5 μm (Huang and Lim 2006). Kapok fibers are fluffy, light-weight, and too inelastic to be spun, and so they are good for stuffing beds, pillows, and cushions. Chemical compositions of kapok fiber were differently reported by two groups of researchers. One found that kapok fiber is chemically composed of 64% cellulose, 13% lignin, and 23% pentosan on a weight basis (Kobayashi et al. 1977), while the other found that it comprises of 35% cellulose, 21.5% lignin, and 22% xylan; kapok fiber has 13% of acetyl groups on a weight basis (Hori et al. 2000). The difference might be due to kapok sources and processing techniques. Besides all those mentioned chemical compositions, they also contain a waxy cutin on the fiber surface which makes them water repellent and oil absorbent. Thus, they are also useful in oil removal applications (Hori et al. 2000; Khan et al. 2004; Huang and Lim 2006; Rengasamy et al. 2011).

There are few reports on utilizing blended kapok fibers for papermaking, such as a case in which blends of 75:25 (w/w) kapok fibers:bamboo pulp were treated with detergent and sodium hydroxide before being used to produce paper (Malab et al. 2001). In this case, the combination of the two non-wood fibers significantly reduced the volume of the bamboo pulp, and the amounts of chemical reagents and energy consumption, without adversely affecting the paper strength properties. Another study has indicated that kapok fibers could potentially be pulped to produce paper (Chaiarrekij et al. 2008), but this claim has not been established, and no products have been further characterized. However, it has been observed that paper sheets made from kapok pulp seemed to demonstrate superior water resistant behavior even without any sizing agents having been added.

Consequently, the optimum set of pulping conditions for the kapok fibers to give the best strength properties was investigated. This optimal set of pulping conditions was then employed to produce kapok pulp. The influence of kapok pulp on paper properties when the kapok pulp was mixed with commercial hardwood pulp and softwood pulp was also determined. The hypothesis being tested was that kapok pulp might increase the strength properties of the hybrid paper prepared from mixtures of kapok pulp with conventional commercial softwood pulp and/or hardwood pulp. It was thought that as well as providing better strength, paper made of kapok pulp might possess superior water resistance, which is generally required for a packaging paper.

## EXPERIMENTAL

### Materials

Before pulping, the kapok fibers (sourced from the north eastern part of Thailand) were cleaned and then fully immersed in tap water for three weeks prior to manually squeezing out the excess water and cutting to 3-5 cm in length. The moisture content was determined using the moisture balance (FD-600, Kett Electric Laboratory, Japan). The commercial bleached softwood (SW) pulp from Pine and bleached hardwood (HW) pulp from Eucalyptus were obtained from the Crofton Pulp & Paper Mill, Canada and the Phoenix Pulp & Paper Public Co., Ltd, Thailand, respectively.

### Methods

The experiment was divided into 2 parts. The first part was about determination of optimal pulping condition for kapok fiber, while the second part was about examining the effects of kapok pulp addition to commercial softwood and hardwood pulps on the properties of the resultant pulp and paper.

*Determination of optimal pulping condition for kapok fiber*

Kapok fibers were separately pulped using 10, 15, 20, and 25% (w/w) NaOH, based on the oven-dried pulp weight. The liquor-to-wood ratio was 17:1. The pulping was carried out in an autoclave digester, (UEC-2017A, Universal Engineering, India) with an initial digesting temperature at 40 °C. The pulp matrix was then gradually heated to 120 °C over 30 min. Pulping was continued at this temperature for another 120 min.

The pulp was then extensively washed with tap water to remove the alkalinity from the pulp by controlling with a pH meter (Hanna HI 98128, Hanna Instrument, U.S.A.).

Kapok pulps were refined twice through a disc refiner, using a 1/100 inch disc gap (Andritz Sprout, U.S.A.). The degree of refining was determined following the Canadian Standard Freeness (CSF) standard, using a freeness tester (CF/A, Regmed, Brazil) according to TAPPI Standard Method T227 om-04. Kapok pulps were disintegrated in a standard disintegrator (Formax T-100, Adirondack, U.S.A.) for 100,000 revolutions in hot water (80 °C) to remove latency. The average length of 5,000 fibers per sample was automatically determined using a fiber quality analyzer (FQA, Optest, Canada) according to the TAPPI Standard Method T271 om-98 using the following equations.

The arithmetic average length of individual fibers ($L$) was calculated from Eq. (1):

$$L = \frac{\Sigma n_i l_i}{\Sigma n_i} \qquad (1)$$

The length-weighted average length of the fibers ($L_l$) was calculated from Eq. (2):

$$L_1 = \frac{\Sigma n_i l_i^2}{\Sigma n_i l_i} \qquad (2)$$

The mass-weighted average length of the fibers ($L_w$) was calculated from Eq. (3):

$$L_w = \frac{\Sigma n_i l_i^3}{\Sigma n_i l_i^2} \qquad (3)$$

In these equations the number of fibers ($n_i$) is the number of fibers in each class of length ($l_i$).

The chemical composition of each pulp was determined using TAPPI Standard Method T222 om-98 for lignin determination, TAPPI Standard Method T203 cm-99 for alpha cellulose (α-cellulose) determination, and Browning's method for holocellulose determination (Browning 1963). The amount of hemicellulose was calculated from the difference between the holocellulose content and the alpha cellulose content.

Kapok pulp was also made into 60 g/m$^2$ handsheets on a Rapid-Köthen sheet former (RK-2A KWT, PTI, Austria) according to the ISO Standard Method 5269-2. The brightness and opacity of the handsheets were measured using an optical tester (Color Touch PC, Technidyne, U.S.A.), based on ISO Standard Methods 2470 and 2471, respectively. The tensile, burst, tear, and zero-span tensile strengths were measured using a tensile strength tester (Strograph E-S, Toyo Seiki, Japan), a burst strength tester (SE002P, Lorentzen & Wettre, Sweden), a tear strength tester (Protear, Thwing-Albert, U.S.A.), and a modified tensile strength tester (Pendulum Tensile Strength Tester with special clamps adjustable to zero, Toyo Seiki, Japan), according to TAPPI Standard Method T494 om-01, T403 om-02, T414 om-04 and T231 cm-96, respectively. The contact angle of water in contact with surface of the handsheet was automatically measured using the Pocket Goniometer PG-3 (Fibro System, Sweden) by capturing and processing the water droplet images. The dynamic mode was used to measure the rate of change of the contact angle as a function of time. The test was done by following TAPPI standard T558 om-06.

*The effects of the addition of kapok pulp to commercial softwood pulp and hardwood pulps on the properties of the resultant paper samples*

Kapok pulp produced by using the set of optimal conditions previously described was bleached using 3% (w/w) aqueous hydrogen peroxide at a 1.5% consistency and 80 °C for 120 min. The product was disintegrated using a disintegrator (Formax T-100, Adirondack Machine, U.S.A.) for 100,000 revolutions in hot water (80 °C) to remove latency. Each commercial pulp was beaten in a valley beater (UEC-2018A, Universal Engineering, India) in which 360 g of the oven-dried pulp in 23 L of water was accommodated, according to TAPPI Standard method T200 sp-01. The softwood pulp and hardwood pulp were separately beaten to meet the Canadian Standard Freeness of 350 mL and 300 mL, respectively. Then, the bleached kapok pulp was mixed with the commercial beaten hardwood pulp, softwood pulp, and mixed pulp (25:75 (w/w) softwood: hardwood) to make 60 g/m$^2$ handsheets. These procedures of papermaking and paper characterization were repeated in the manner as previously described.

*Statistical analysis*

Parametric data were analyzed using the analysis of variance (ANOVA). In all cases, a p-value smaller than or equal to 0.05 was accepted as being a statistically significant difference. For all of the experiments, three replicates were performed.

## RESULTS AND DISCUSSION

### Determination of Optimal Pulping Condition

*Chemical composition of kapok pulp*

The effects of the sodium hydroxide solution on the chemical composition of the kapok pulp are summarized in Table 1. Analysis of the chemical composition of the pulps showed that an increased amount of sodium hydroxide in cooking liquor resulted in lower percentages of lignin, higher percentages of holocellulose and alpha cellulose, with lower percentages of hemicellulose. It should be noted that holocellulose is composed of alpha cellulose and hemicellulose. This finding was to be expected, since sodium hydroxide solution dissolves lignin. Carbohydrates, especially hemicellulose, can also be easily destroyed by sodium hydroxide, leaving a higher ratio of alpha cellulose behind. Since all of the P-values of the chemical compositions were lower than 0.05, the effects of sodium hydroxide solution on kapok pulp chemical compositions were thus statistically significant.

**Table 1.** Effects of Sodium Hydroxide Concentration on the Chemical Composition of the Kapok Pulp

| Pulp Chemical Composition | NaOH Dosage (% w/w) | | | | |
|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | P-value |
| Lignin (%) | 19.20 | 18.27 | 17.57 | 17.53 | 0.0109* |
| Holocellulose (%) | 76.12 | 76.53 | 78.49 | 78.50 | 0.0005* |
| Alpha cellulose (%) | 65.63 | 69.87 | 69.65 | 69.96 | 0.0002* |
| Hemicellulose (%) | 10.49 | 6.66 | 8.84 | 8.54 | 0.0007* |
| * Statistically significant since P-value is lower than 0.05 | | | | | |

*Kapok pulp and fiber characteristics*

The effects of sodium hydroxide treatment level on pulp yield, freeness and the average fiber length, characterized in terms of arithmetic, length-weighted, and mass-weighted criteria, are summarized in Table 2, along with the percentage of fines.

**Table 2.** Pulp and Fiber Characteristics of the Kapok Pulp after Soda Pulping

| Pulp and Fiber Properties | NaOH Dosage (% w/w) | | | |
|---|---|---|---|---|
| | 10 | 15 | 20 | 25 |
| Pulp yield (%) | 62.40 | 51.25 | 44.69 | 40.46 |
| Freeness (CSF, mL) | 401 | 362 | 296 | 277 |
| Average fiber length-Arithmetic (mm) | 0.91 | 0.91 | 0.83 | 0.81 |
| Average fiber length-Length-weighted (mm) | 1.51 | 1.49 | 1.32 | 1.28 |
| Average fiber length-Mass-weighted (mm) | 2.26 | 2.17 | 1.93 | 1.83 |
| Fines (%) | 21.5 | 21.6 | 22.7 | 23.7 |

The results in Table 2 indicate that high sodium hydroxide concentration could also result in lower pulp yield because of the removal of lignin and extractives. Also, high sodium hydroxide dosage could lead to carbohydrate degradation, especially with the hemicellulose, due to a peeling reaction (Sjöström 1993). This might also contribute to lower pulp yield.

Table 2 shows that increasing the concentration of sodium hydroxide significantly decreased the degree of the pulp freeness. Thus, there was a decrease in the pulp's drainage capacity. This was probably due to an increasing amount of fines, which would have a significantly greater surface area than fibers for water absorption. With an increasing amount of fines, the pulp becomes more difficult to dewater (Höglund 2009). Also relevant are the removal of hydrophobic lignin, the dissolution of hemicellulose and possibly the saponification of the cutin wax by the alkali with "solvation" of the cellulose. The latter two possibilities were supported by the results from contact angle studies in which the contact angle with water decreased when the amount of alkali was increased (Fig. 1).

Figure 1 also shows that the handsheets in the dry state (at a zero contact time) had the greater water contact angles. However, after contact with the water, the contact angles decreased due to wetting, absorption, penetration, and spreading of the water under the influence of the cellulosic hydrophilic interactions.

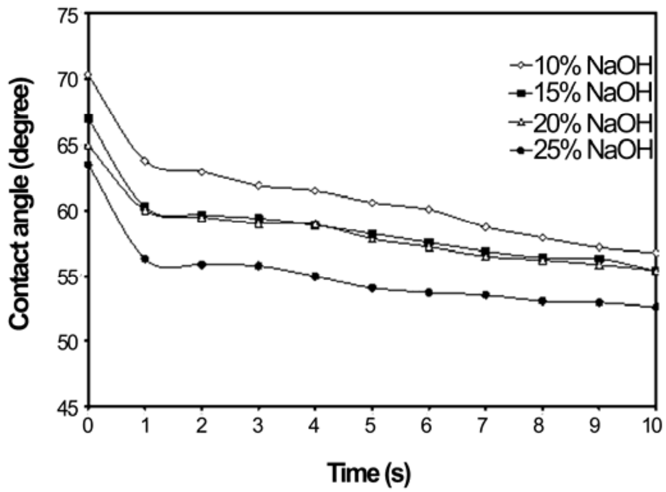


**Fig. 1.** Effects of different sodium hydroxide concentrations on water contact angles of the kapok fiber sheets

It should be noted that mass-weighted average fiber length is one of the average fiber length values, but it places more emphasis on the content of long fibers as compared to the length-weighted fiber length and the arithmetic average fiber length, respectively. When the amount of sodium hydroxide increased, the average fiber length significantly decreased, whilst the fines content was increased (Table 2). This was likely to have occurred because the fibers were damaged by a peeling reaction under the strong alkali conditions, leading to carbohydrate degradation. Thus, the greater the amount of carbohydrate that was degraded by the alkali, the lower would be the mean fiber length and the greater the amount of fiber fines would be.

*Kapok handsheet properties*

The effects of the sodium hydroxide solution on the kapok handsheet properties are summarized in Table 3.

**Table 3.** Effects of Sodium Hydroxide Concentration on the Kapok Handsheet Properties

| Pulp and Paper Properties | NaOH Dosage (% w/w) | | | | |
|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | P-value |
| Apparent density (g/cm$^3$) | 0.68 | 0.80 | 0.82 | 0.88 | 0.1264 |
| ISO opacity (%) | 97.9 | 97.5 | 97.4 | 97.0 | 0.0235* |
| ISO brightness (%) | 21.3 | 19.1 | 18.6 | 18.1 | 0.1917 |
| Tensile index (N m/g) | 80.3 | 100.4 | 111.5 | 101.3 | 0.0002* |
| Elongation (%) | 1.75 | 2.01 | 2.10 | 2.05 | 0.0335* |
| Burst index (kPa m$^2$/g) | 4.44 | 5.73 | 5.96 | 5.98 | 0.0348* |
| Tear index (mN m$^2$/g) | 1.78 | 1.68 | 1.60 | 1.59 | 0.4005 |
| Zero span tensile index (N m/g) | 59.5 | 58.2 | 56.7 | 55.9 | 0.9801 |

* Statistically significant since P-value is lower than 0.05

Increasing the amount of sodium hydroxide solution led to an increase in the apparent density of the sheets, which was defined as handsheet grammage divided by handsheet thickness, but a lower opacity (Table 3). Such effects are likely to be due to the role of sodium hydroxide solution in breaking up lignin molecules within the fiber cell wall. As the hydrophobic lignin was removed, the fiber surface became more hydrophilic, encouraging fiber swelling and conformability. This would result in a more compacted sheet, which in turn could lead to fewer air-to-fiber interfaces and a lower opacity. In addition, the increasing content of fines and the greater amount of fiber contact areas would help to improve fiber bonding, leading to denser sheets, as indicated by the higher apparent density. Shorter fibers and a greater amount of fines also provided a basis for more effective filling of existing voids, which might also have contributed to lower opacity of the sheet. However, the effect of sodium hydroxide solutions on the apparent density appeared in this case to be statistically insignificant, while its effect on opacity was statistically significant.

Pulp brightness would be expected to increase when greater amounts of sodium hydroxide solution were used, since more lignin would be removed. However, the observed trend was the opposite to this expectation, as indicated by the statistical evaluation (Table 3). However, greater concentrations of sodium hydroxide solution might reduce pulp brightness through an alkali darkening reaction, resulting in structural changes of the chromophoric groups in the residual lignin. The chromophoric groups are unsaturated structures and color contributing groups. Generally, these chromophoric groups are derived from various structures types such as phenols, catechols, and quinine in combination with unsaturated systems of styrene, diphenylmethane, and butadiene structures (Sjöström 1993). In the presence of alkali, the absorption maxima of some types of chromophoric groups are shifted to higher wavelengths due to the ionization of phenolic hydroxyl groups (Gellerstedt 1996). This shift increases the color intensity, and the effect still persists after pulping and washing, thus causing the brightness of the pulp to decrease. An additional possible explanation might be that the sodium hydroxide solution mediated the removal of lignin and caused greater sheet compactness with a resultant reduced level of light scattering of the sheet, whilst the greater amount of fines might also lead to sheet compactness.

The tensile index defines the tensile strength of paper. It is the tensile strength divided by the grammage. The burst index defines the burst strength of the paper and is equal to the burst strength divided by the grammage. Fiber bonding is highly likely to affect the tensile strength and burst strength. Increasing sodium hydroxide dosage provided higher tensile and burst strengths due to increasing fiber bonding, since lignin was removed and fibers became more conformable (Table 3). Increased fiber bonding caused by the greater sodium hydroxide dosage also led to the higher elongation. However, it should be noticed that using too high dosage of sodium hydroxide was detrimental to tensile and burst strengths as a result of carbohydrate degradation by peeling reaction at a strong alkali condition. The effects of the sodium hydroxide concentration in cooking liquor on the tensile index, the elongation and the burst index were statistically significant.

The tear index, the tear resistance value divided by the grammage, defines the tear resistance of the paper. Tear resistance is affected by many factors, such as the intrinsic fiber strength, the fiber length, and fiber bonding. The most important factor for well-bonded sheets is the fiber strength. The zero span tensile index is defined by the zero-span tensile strength divided by the grammage. Generally, zero span tensile index is a function of both the intrinsic fiber strength and the fiber bonding; however, the intrinsic fiber strength is a major contributing factor. The tear index decreased when the sodium hydroxide concentration increased (Table 3). The same observation was found for the zero span tensile index. This effect could be caused by the peeling reaction, which works from the end of a cellulose or hemicellulose chain, breaking down the molecule by alkaline hydrolysis, thus leading to a drop in the degree of polymerization of the fibers (Shatalov and Pereira 2005). The decrease in tear resistance might also be caused by the shorter fiber length and the greater amount of fines that are created. However, the effects of sodium hydroxide dosage on the tear and zero span tensile index values were so small that they were statistically insignificant.

Overall, the optimum condition for kapok fiber pulping was that of the cooking liquor containing 20% (w/w) of sodium hydroxide, which gave the maximum tensile properties as discussed. Thus, kapok pulp that was prepared using a 20% (w/w) sodium hydroxide dosage was used in subsequent experiments. However, the pulp was bleached before being mixed with commercial pulps.

## Effects of Kapok Pulp Addition to Commercial Softwood and Hardwood Pulps on the Properties of the Resultant Pulp and Paper

*Fiber length distributions of kapok, softwood and hardwood pulps*

The fiber length distributions of the kapok pulp that was produced using the cooking liquor of 20% (w/w) sodium hydroxide and the commercial softwood pulp and hardwood pulp are shown in Fig. 2.

The kapok pulp had an intermediate amount of short fibers, which was less than that of the hardwood pulps. The softwood pulp gave the lowest short fiber content. The kapok pulp was also intermediate in the amount of both medium and long fibers. These were lower than that from the hardwood pulp. The softwood pulp contained the greatest amount of long fibers.

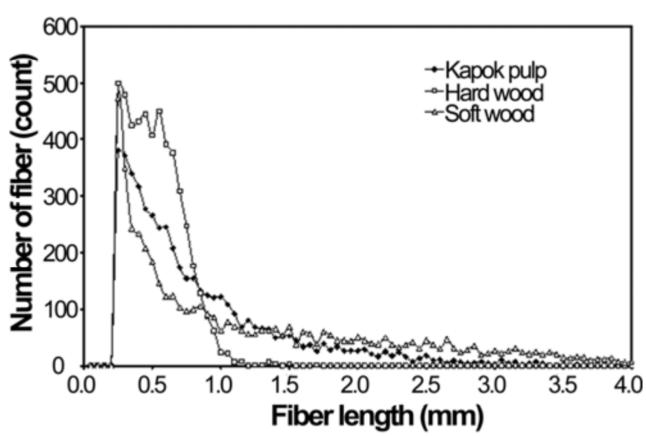


**Fig. 2.** Fiber length distributions of the kapok, hardwood and softwood pulps.

*Fiber length, fines content and zero span tensile index of kapok, softwood and hardwood pulps*

Fiber length, fines content and zero span tensile index of kapok, softwood and hardwood pulps are compared in Table 4.

**Table 4.** Fiber Length, Fines Content and Zero Span Tensile Index of Kapok and the Commercial Pulps

| Pulp Properties | Pulp Types | | |
|---|---|---|---|
| | Kapok | Softwood (SW) | Hardwood (HW) |
| Average fiber length-Arithmetic (mm) | 0.83 | 1.25 | 0.50 |
| Fines (%) | 22.7 | 43.2 | 34.0 |
| Zero span tensile index (N m/g) | 56.7 | 82.6 | 44.2 |

After being refined to the freeness of 300 mL, as shown in Table 4, the average fiber length of the kapok pulp (0.834 mm) was between those of the softwood pulp (1.253 mm) and hardwood pulp (0.496 mm). The kapok pulp also had the lowest level of fines, followed by the hardwood pulp and softwood pulp, respectively.

As shown in Table 4, the sheets made from the softwood and hardwood pulps had the greatest and least zero-span tensile index at 82.6 and 44.2 N m/g, respectively. That made from kapok pulp reached 56.7 N m/g. Since kapok fiber was brittle, this led to the lower zero span tensile index of kapok pulp.

*Apparent density*

The apparent densities of the sheets that were prepared from different ratios of the kapok pulp to the commercial softwood (SW), hardwood (HW) and softwood-hardwood mixed pulps, are shown in Fig. 3.

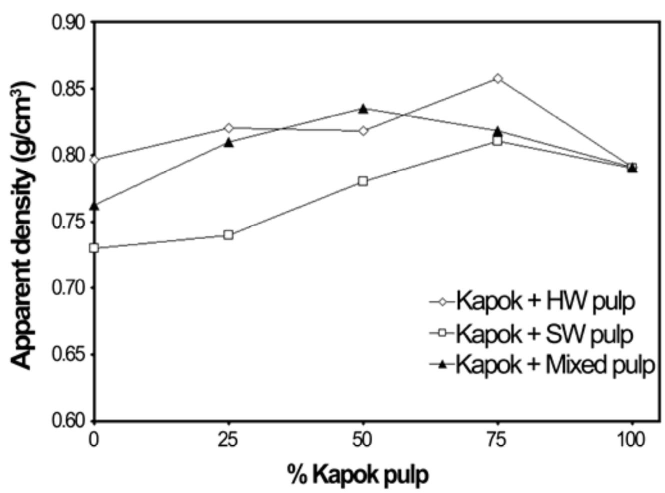


**Fig. 3.** Apparent density of the sheets made from kapok pulp mixed with the commercial hardwood (HW) pulp and softwood (SW) pulp at the indicated percentages

The sheets made from the hardwood pulp had a greater apparent density than those containing either the softwood pulp or the kapok pulp. That is because the shorter fibers of the hardwood pulp fill the voids and pores in the sheet structure, making the sheets more compact. The inclusion of kapok pulp increased the apparent density of the sheets in all of the pulp mixtures. This could be because the kapok fibers have very thin cell wall, being easily collapsed, making more compact sheets. However, sheets derived from pure kapok pulp were not greater in apparent density, as seen by the fact that the kapok fibers become easily entangled. Thus, pure kapok sheets gave poor sheet formation and an irregular sheet surface.

*Tensile index and burst index*

The sheets made from kapok pulp gave the highest tensile index (Fig. 4). This could be because the kapok fibers were long and the lumens were easily collapsed when forming paper, producing highly bonded regions and denser sheets with a resulting superior sheet tensile index.

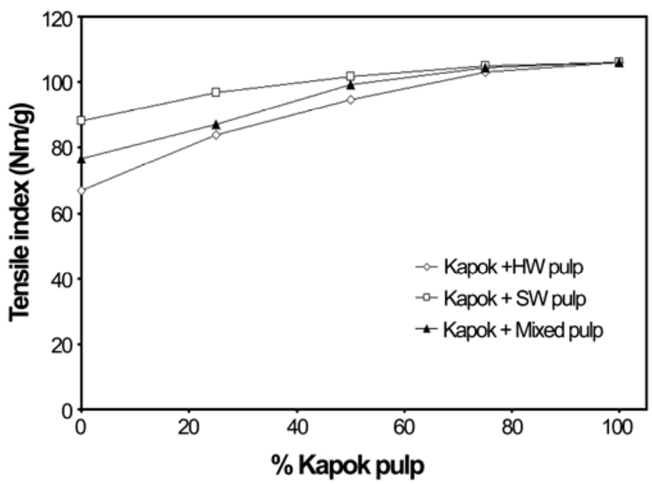


**Fig. 4.** Tensile index of the sheets made from kapok pulp mixed with the commercial hardwood (HW) pulp and softwood (SW) pulp at the indicated percentages

The sheets made from the hardwood pulp exhibited the lowest tensile index. Those made from a 75:25 (w/w) blend of the hardwood:softwood pulps had a medium tensile index. Those made from the pure softwood pulp achieved the greatest tensile index. With respect to kapok-commercial pulp mixtures, as the ratio of kapok pulp increased, the tensile index also increased (Fig. 4). However, the results were more prominent when the kapok pulp was mixed with the hardwood pulp than with the softwood pulp.

The sheets derived from pure kapok pulp gave the highest burst index, the values being somewhat similar to those of the sheets made from the softwood pulp (Fig. 5). This is because both kapok fiber and the softwood fiber are long and have extensive contact areas that are available for fiber bonding. The sheets made from the hardwood pulp had the lowest burst index. This is because the hardwood pulp contained a greater amount of short fibers, resulting in poor bonding. As the ratio of the kapok pulp in mixtures with the hardwood pulp or the 75:25 ratios (w/w) of hardwood pulp: softwood pulp increased, the burst indexes of the resultant paper significantly increased, because fiber bonding was greatly improved.

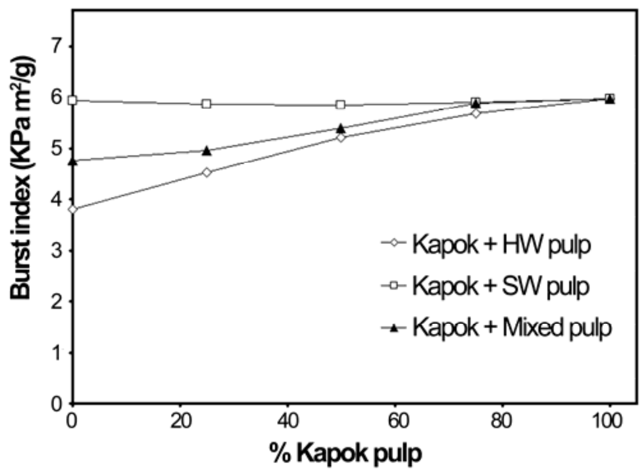


**Fig. 5.** Burst index of the sheets made from kapok pulp mixed with the commercial hardwood (HW) pulp and softwood (SW) pulp at the indicated percentages

*Tear index and elongation*

One of the key characteristics of kapok fibers is their brittleness. Thus, the sheets made from the kapok pulp had the lowest tear index relative to those made from the commercial softwood pulp, the hardwood pulp, and the softwood-hardwood mixed pulp.

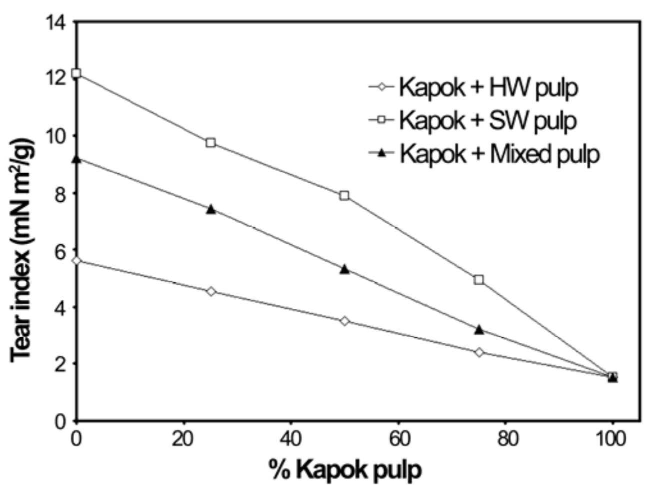


**Fig. 6.** Tear index of the sheets made from kapok pulp mixed with the commercial hardwood (HW) pulp and softwood (SW) pulp at the indicated percentages

For kapok-commercial pulp mixtures at different ratios, it was clearly observed that as the ratio of kapok pulp increased, the tear index significantly decreased (Fig. 6).

The elongation of the sheets that were prepared from different ratios of the kapok pulp is compared in Fig. 7. Sheets made from kapok pulp had the lowest elongation. This is because the key characteristics of kapok fibers are their brittleness and inelasticity, which might reduce the elongation of the sheets when a load was applied. Thus, as the ratio of the kapok pulp was increased, the elongation significantly decreased in all pulp mixtures.

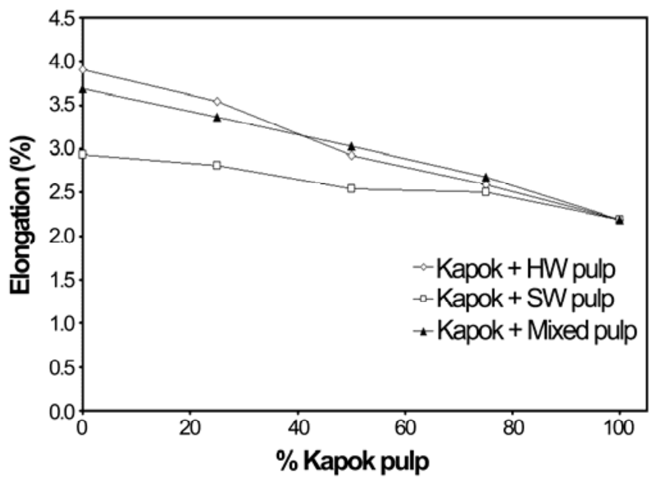


**Fig. 7.** Elongation of the sheets made from kapok pulp mixed with the commercial hardwood (HW) pulp and softwood (SW) pulp at the indicated percentages

*Water contact angle*

The water contact angles of the sheets made from kapok pulp mixed with the commercial softwood pulp and hardwood pulp are shown in Fig. 8. As seen in Fig. 8, K 100 represents handsheets made from 100% kapok pulp. HW100 refers to handsheets made from 100% hardwood pulp while SW100 refers to handsheets made from 100% softwood pulp. M100 designates handsheets made from mixed commercial pulp (25:75 (w/w) softwood pulp: hardwood pulp). Handsheets prepared from kapok pulp mixed with hardwood, softwood and mixed pulps with different percentages are characterized by K:HW, K:SW, and K:M, with the percentage indicated in parenthesis.

The results indicated that as the time of contact increased, the water contact angles decreased because of absorption and penetration of the water droplets into the sheet. Those made from 100% kapok pulp gave the greatest values for the water contact angle. This effect was due to the unique characteristics of the kapok fibers having a wax coating on the surface. Although the kapok fibers were pulped, some of the wax was still present. When mixed with the commercial pulps (softwood, hardwood and mixed pulps), as the ratio (w/w) of the kapok pulps increased, the water contact angle values increased.

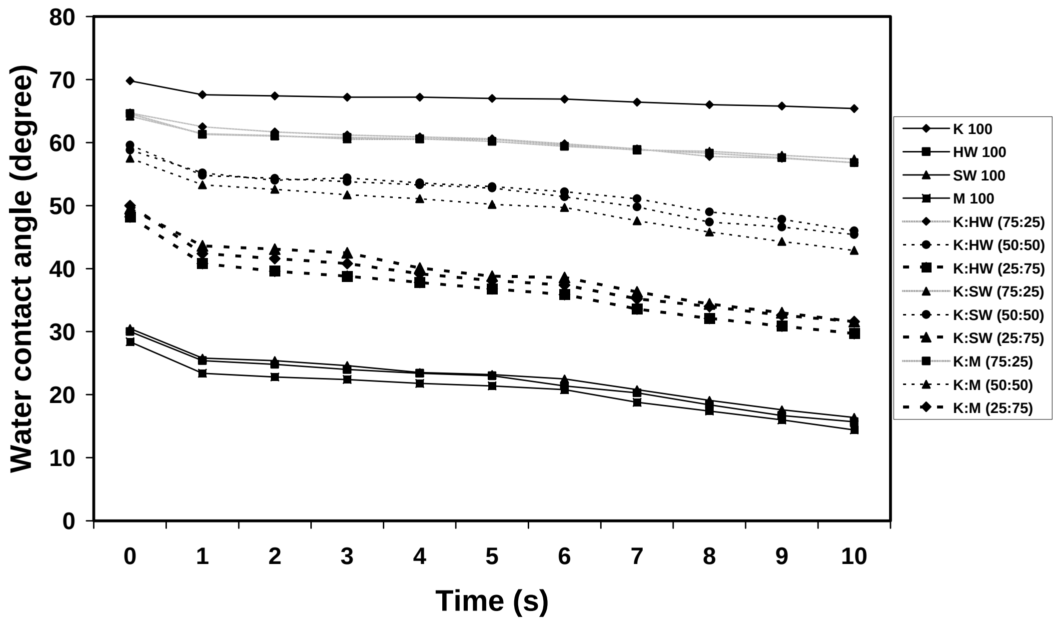


**Fig. 8.** Water contact angles of the sheets from the kapok (K) pulp mixed with the commercial hardwood (HW) pulp, softwood (SW) pulp and mixed (M) pulp at the indicated percentages

## CONCLUSIONS

1. When kapok pulp was mixed with the commercial softwood pulp and/or hardwood pulp, the tensile and burst strengths of the blended sheets increased but with the lower tear resistance and elongation due to the high bonding ability and brittleness of the kapok pulp.
2. Handsheets containing kapok pulp gave greater water contact angles due to the hydrophobic nature of kapok fibers.
3. Thus, kapok pulp can potentially be mixed with the commercial softwood pulp and/or hardwood pulp to produce commercial packaging paper when the strength, water repellency and light weight characteristics are required.

## ACKNOWLEDGMENTS

This research was financially supported by a Research Team Aid Grant from the Thailand Research Fund and Commission of Higher Education under the contract number RTA5080004. The authors would like to thank the Department of Imaging and Printing Technology of Chulalongkorn University, and the Product and Technology Development Center of Siam Cement Group Paper Company Limited for providing relevant research facilities.

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Article submitted: February 13, 2011; Peer review completed: April 12, 2011; Revised version received and accepted: November 22, 2011; Published: November 27, 2011.