

## EVALUATION OF LINERBOARD PROPERTIES FROM MALAYSIAN CULTIVATED KENAF SODA-ANTHRAQUINONE PULPS VERSUS COMMERCIAL PULPS

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Malaysian cultivated kenaf has been identified as a suitable raw material for linerboard production. This study examines the soda-antraquinone (soda-AQ) pulp of kenaf fibers versus old corrugated container (OCC) and unbleached softwood kraft pulps as the main sources for linerboard production. The results showed significant differences among the pulp properties. The unbleached kraft pulp with very high freeness required high beating to reach an optimized freeness and produced paper with the highest strength properties, except for tear resistance. The OCC gave paper with the lowest strength properties. In the case of kenaf fractions, bast pulp with high freeness needed less beating than softwood and produced paper with high tear resistance. Core fiber, which had the lowest freeness and highest drainage time, led to paper with high strength but very low tear resistance. Kenaf whole stem pulp showed intermediate properties between core and bast and close to those of unbleached softwood pulp, but with very lower beating requirement. Finally, kenaf whole stem, due to its strength properties, moderate separation cost, and simple pulping process, was judged to be more suitable for commercialization for linerboard production in Malaysia.

*Keywords:* Malaysian cultivated kenaf; Soda-AQ pulp; OCC; Unbleached softwood kraft pulp; Linerboard

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### INTRODUCTION

Malaysia has a rather weak pulp and paper industry, the production capacity of which does not satisfy the domestic consumption. The country is a net importer of pulp, paper, and paperboard. For instance, almost 50% of the total paper consumption comes from packaging papers such as kraft liner and corrugating medium. However, there is no local production of kraft pulp in Malaysia, and this implies a high reliance on imports (Koay and Leh 2007). On the other hand, the government has actively encouraged the paper and paper board industry to become self-sufficient and to reduce the import of pulp, paper, and board (Jalaluddin et al. 2009). So, the insufficient supply of fiber for papermaking has necessitated the paper industry to search for alternative fiber sources such as recycling of waste paper and the utilization of non-wood fibrous plants.

Currently, recycled paper and boards are important sources of material for the pulp and paper industry in Malaysia. For instance, old corrugated containers (OCC) has the highest recycling recovery rate of (70%) among all recycled paper grades and are the predominant fiber sources for linerboard production in Malaysia (Mas'ut 2009). However, process problems, product quality, and cost effectiveness will still be great challenges in the recycling of waste paper (Cardellini et al. 2006).

On the other hand, kenaf has been identified as one of the potential sources for pulp fibers, and some research has been carried out based on locally available kenaf in the production of pulp and paper (Ashori 2006; Sharmiza et al. 2005; Mohd Nor et al. 2004). Moreover, our earlier study (Azizi Mossello et al. 2010) showed that Malaysian cultivated kenaf has potential for linerboard production. The present study compares linerboard properties from kenaf kenaf fibers (bast, core and whole) versus old corrugated container (OCC) and unbleached softwood kraft pulps, which mainly are used for linerboard production in Malaysia

## EXPERIMENTAL

### Materials

The unbeaten kenaf soda-AQ pulps, i.e. core, bast, and whole stem [kenaf high Kappa (KHK) and kenaf low Kappa (KLK)] pulps (Table 1) were prepared from our earlier study (Azizi Mossello et al. 2010). Commercial pulps, i.e. old corrugated containers (OCC) with kappa number 61.2, and unbleached softwood kraft pulp (USWK) with Kappa number 26.19, were obtained from Pascrop Paper Berhad, Malaysia and Mazanderan Wood and Paper Industries, Iran, respectively.

**Table1.** Soda-AQ Pulping Result for Malaysian Cultivated Kenaf fractions

Pulp	Cooking condition		Pulp quality			Remark
	A.A. (%)	Time (min)	Kappa no.	Reject (%)	Total yield (%)	
Whole	12	60	49.4	1.8	58.0	kenaf high Kappa
Whole	15	60	25.4	0.2	54.9	kenaf low Kappa
Core	15	60	29.5	0.1	51.8	
Bast	15	60	20.2	0.1	56.2	

A.A.- active alkali as Na<sub>2</sub>O; Cooking temperature, 160 °C; liquor to raw material, 7:1; AQ, 0.1%

### Methods

#### *Pulp beating*

Beating of screened pulp samples was done in a PFI mill at the pulp and paper laboratory in the Forest Research Institute Malaysia (FRIM) according to TAPPI T 248 sp-00. In this research the core pulp, due to its low freeness (291 mL CSF), was used as unbeaten pulp. Kenaf whole stem pulps (Khristova et al. 2002; Aravamuthan et al. 2002) and OCC (Nazhad and Sotdivarakul 2004) were beaten to freeness 300 mL CSF. USWK was beaten to an optimized freeness of 400 mL CSF (Dehghani Firouzabadi et al. 2008). Bast pulp was beaten at 1000, 2000, and 3000 revolutions (Villar et al. 2009), and paper from optimized freeness pulp was chosen for comparison.

### *Fiber length determination*

The samples of beaten pulps were boiled in water in separated beakers to remove air from the fibers and then placed in separated test tubes containing an equal amount of glacial acetic acid and 35% hydrogen peroxide, an approach similar to that followed by Franklin (1945). Fiber length was measured based on an average of 50 measurements by using a Quantimeter Image Analyzer equipped with a Lecia microscope and Hipad digitizer (from Quantimet 520, Cambridge Instruments) at the fiber anatomy laboratory in the Faculty of Forestry, University Putra Malaysia (UPM).

### *Paper characterization*

The standard drainage time of the pulps was determined according to TAPPI method T 221 cm-99. The handsheets with basis weight of 150g/m<sup>2</sup> were made in a British handsheet former according to TAPPI T 205 sp-02 and tested for tear index (TAPPI T 414 om-98), tensile index (TAPPI T 494 om-01), burst index (TAPPI T 403 om-97), and ring crush test (RCT) (TAPPI T 822 om-02). Light scattering coefficient was measured using a Color Touch™ model ISO (Technidyne Corporation) spectrophotometer according to TAPPI T425 om-01. The surface structure of handsheets was observed using Scanning Electron Microscopy (SEM) at the pulp and paper laboratory in FRIM.

### *Statistical analysis*

The paper properties experiment was done as a Completely Randomized Design with six pulps as treatment. Analysis of variance and Duncan's Multiple Range Test were done to show significant differences between treatments. Statistical procedures were carried out using SPSS software.

## **RESULTS AND DISCUSSION**

### **Beating Response**

Figure 1 illustrates the variation of pulp freeness with PFI mill revolutions. Surface area is known to affect the freeness. As the surface area increases, the freeness decreases. Beating with fiber shortening, fiber fibrillation, and fines generation increases fiber surface area and is responsible for the decreased freeness (El- Hossieny and Yan 1980). USWK had the highest freeness (740 mL CSF) and due to very strength fibers requires extensive beating (7000 PFI rev.) to lower the freeness to 400 mL CSF (Dehghani Firouzabadi et al. 2008; Bhardwaj et al. 2007). OCC, due to its hornified fibers, had relatively high freeness (470 mL CSF) and took 2000 PFI revolutions to lower the freeness to 300 mL CSF (Nazhad and Sotivarakul 2004).

In the case of kenaf pulps, bast pulp showed high freeness (640 mL CSF) but required less beating level than USWK (3000 vs. 7000 PFI rev.) to achieve an optimized freeness (350 mL CSF). This can be explained, since unlike wood fibers whose fibrils are spirally wound, fibrils of bast fibers lie generally parallel to the fiber axis (Sabharwal et al. 1994) and need only a fraction of the beating required for a softwood pulp to decrease freeness and develop strength properties (Kaldor et al. 1990). On the other hand, core

pulp, due to presence of fines and parenchyma cells with higher surface area, had the lowest freeness and has been suggested to be used as unbeaten pulp (Azizi Mossello et al. 2010; Villar et al. 2009). Whole stem pulps (KHK and KLK) showed intermediate properties between bast and core pulps and needed less beating than OCC pulp to reach a target freeness.

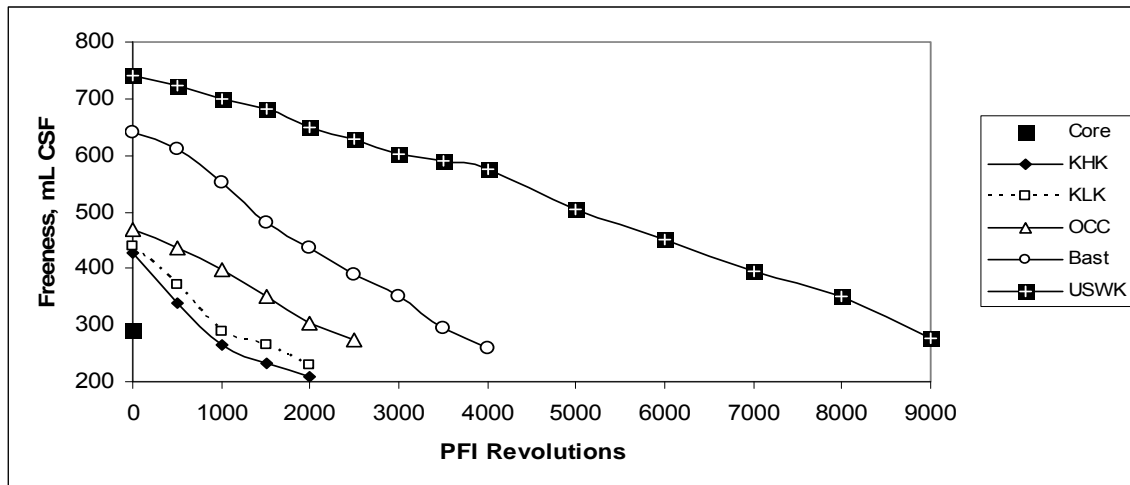


Figure 1. Variation of pulp freeness with PFI mill revolutions

### Improvement of Bast Pulp Properties

The main requirements of linerboard are a high burst strength and high compression strength. Burst strength is a good indicator of the resistance of paper or paperboard to internal mechanical stresses (Nazhad and Sotivarakul 2004). Also, by measuring the compression strength of linerboard in the cross direction, the stacking strength of the final corrugated box can be predicted. The actual test for compression strength can be performed by the RCT method (Karlsson 2006).

The strength properties of a sheet of paper depend on the original qualities and strength of the fibers and also on the extent of bonding between the fibers that make up the sheet. A paper sheet made from unbeaten virgin pulp is characterized by low strength, high bulkiness, and high surface roughness, so it is not suitable for most grades of paper (Bhardwaj et al. 2004). Beating, which involves fiber fibrillation, fiber shortening, and fines generation, increases the fiber surface area and promotes the formation of fiber-fiber bonds, thus leading to an increase in strength properties (Jahan and Rawshan 2009; Dutt et al. 2009; Parker et al. 2005; Bhardwaj et al. 2004).

Table 2 shows linerboard properties of Malaysian cultivated kenaf bast pulp. It can be seen that with increasing beating level all strength properties increased, except for tear resistance, due to improvement of fiber bonding. The improved bonding was also indicated by significantly higher apparent density and lower light scattering coefficient (Hossienpour et al. 2010; Fatehi et al. 2009; Seth 2001). So, pulp with freeness of 350 mL CSF, due to better strength properties, especially Burst and RCT that are very important for linerboard, was selected as representative for kenaf bast pulp.

**Table 2.** Linerboard Properties of Kenaf Bast Soda-AQ Pulp

Parameters	PFI Revolutions		
	1000	2000	3000
Freeness, mL CSF	553a <sup>†</sup>	436b	350c
Apparent density, g/cm <sup>3</sup>	0.545b	0.550b	0.594a
Light scattering coefficient, m <sup>2</sup> /kg	26.87a	24.99ab	24.14b
Tear index, mN.m <sup>2</sup> /g	25.81b	27.26a	23.95c
Tensile index, N.m/g	54.82c	67.46b	72.47a
Burst index, kPa.m <sup>2</sup> /g	3.58c	3.86b	4.70a
RCT, kN/m	1.84b	1.93b	2.61a

<sup>†</sup> Means within a row followed by different letters differ significantly at  $\alpha = 0.05$

### Comparison Linerboard Properties from Kenaf Pulp vs. Commercial Pulps

The linerboard properties of kenaf fractions, OCC, and USWK pulps are shown in Table 3. In comparison to kenaf pulps, USWK due to higher beating (Fig. 1) had more collapsed fibers (see Fig. 3) and higher bonding ability, as indicated by higher density and lower light scattering coefficient (Hossienpour et al. 2010; Fatehi et al. 2009; Seth 2001), leading to paper with the highest strength properties, especially burst index and RCT, as well as good drainage character. In contrast, OCC, due to its more rigid fibers (Latifah et al. 2009; Wanrosli et al. 2005) had the lowest bonding ability, as indicated by lowest density and highest light scattering coefficient, yielding paper with the lowest strength properties, except for tear index.

In the case of kenaf pulps, unbeaten core pulp, due to its short fibers with low Runkel ratio (Azizi Mossello et al. 2009) had efficient sheet formation (Fig. 3a) and fiber bonding, as indicated by low light scattering coefficient and high density, resulting in paper with high strength, but the lowest tear index (Table 3). Opposite of good strength, core pulp because of the presence of fine and parenchyma cells with higher surface area (Azizi Mossello et al. 2010; Villar et al. 2009), had the lowest freeness and highest drainage time, which can effect paper machine speed. In contrast, bast pulp, due to its long, tubular, and relatively uncollapsed fibers (see Fig. 3a and 3b) had low fiber bonding and sheet formation, as indicated by low density and high light scattering coefficient, and gave paper with low strength properties but high tear index (Table 3). Kenaf whole stem, due to its mixture of core and bast fiber that can complement each other (Azizi Mossello et al. 2010; Ververis et al. 2004; Khristova et al. 1998) showed intermediate properties especially tear index between core and bast pulps (see Table 3). Moreover, KLK, due to flexibility which associated with lower lignin content (Yang et al. 2008; Rushdan et al. 2007; Minor et al. 1993) had better inter-fiber bonding and sheet consolidation, as was indicated by lower light scattering coefficient and higher density (Seth 2001), leading to paper with higher strength properties than KHK.

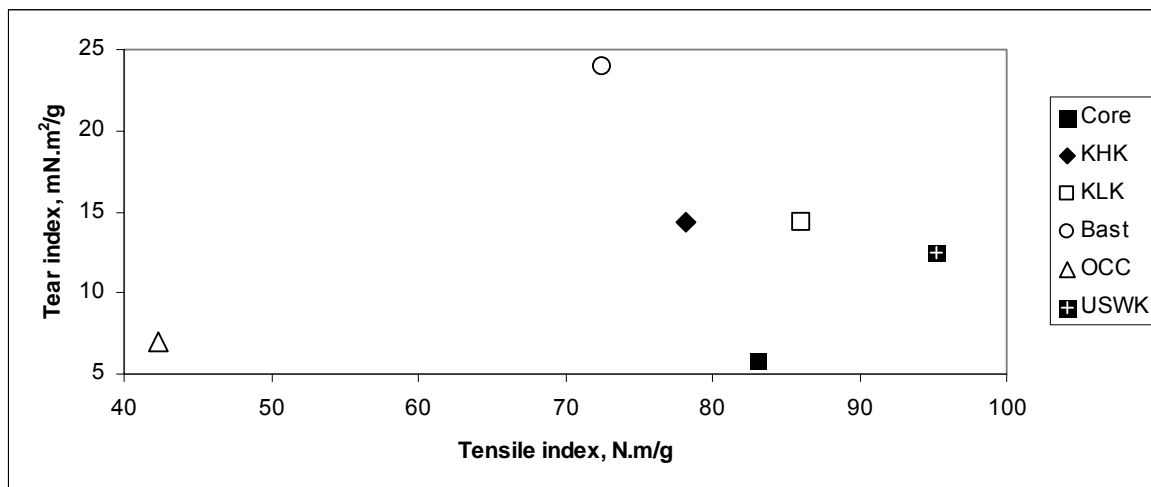
Figure 2 illustrates the relationship between tear and tensile strengths of kenaf fiber pulps and commercial pulps. It can be seen that OCC had the lowest strength properties. In contrast to its low tensile strength, bast showed excellent tear strength. By

contrast, core pulp was the opposite, exhibiting good tensile strength, but the lowest tear strength. Kenaf whole stem pulp showed strength properties between core and bast and even higher tear strength than USWK. It is believed that core and bast can complement each other when used as whole stem and produce pulp with good quality and strength (Azizi Mossello et al., 2010; Ververis et al. 2004; Khristova et al. 1998).

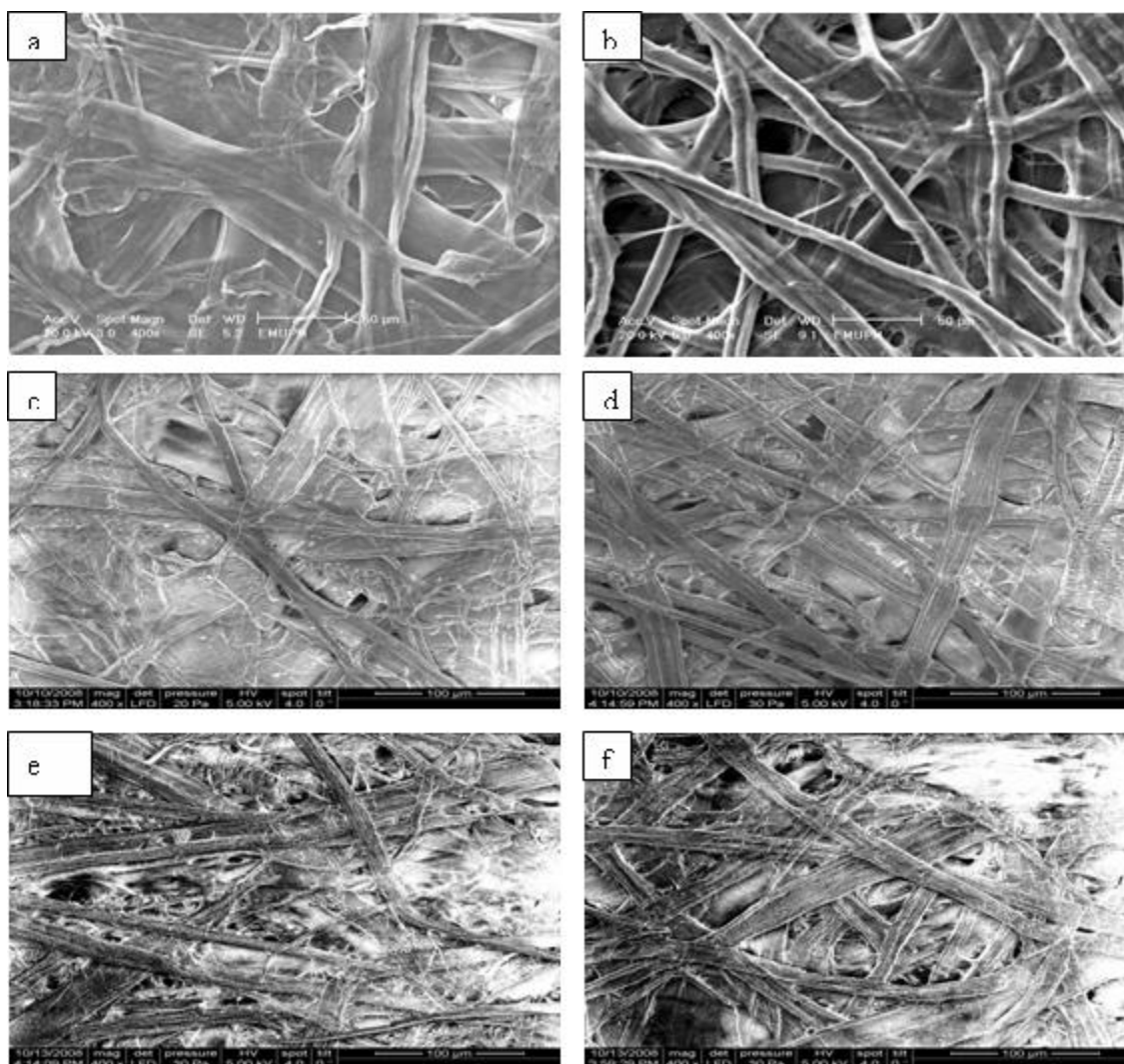
**Table3.** Linerboard Properties of Kenaf Fractions and Commercial Pulps at Optimum Freeness

Parameters	Core	KHK	KLK	Bast	OCC	USWK
Freeness, mL CSF	291	300	300	350	300	400
Fiber length, mm	0.68d <sup>†</sup>	1.38b	1.46b	1.86a	0.98c	1.74a
Drainage time, s	12.52a	10.40c	11.05b	5.92e	8.13d	10.22c
Apparent density, g/cm <sup>3</sup>	0.716a	0.651c	0.672b	0.594d	0.533e	0.723a
Light scattering coefficient, m <sup>2</sup> /kg	16.85e	22.56c	20.06d	24.14b	29.61a	13.34f
Tear index, mN.m <sup>2</sup> /g	5.87e	14.35b	14.36b	23.95a	7.02d	12.49c
Tensile index, N.m/g	83.09b	78.21c	86.10b	72.47d	42.27e	95.18a
Burst index, kPa.m <sup>2</sup> /g	6.09b	5.21c	5.90b	4.70d	2.79e	7.23a
RCT, kN/m	2.87b	2.25d	2.68c	2.61c	1.32e	3.14a

<sup>†</sup> Means within a row followed by different letters differed significantly at  $\alpha = 0.05$



**Figure 2.** Relationship between tear and tensile strengths of kenaf and commercial pulps



**Figure 3.** SEM micrographs of handsheet structure at optimum freeness with magnification 400x for: (a) unbeaten kenaf core soda-AQ with freeness 291 mL CSF, (b) kenaf bast soda-AQ at freeness of 350 mL CSF, (c) kenaf whole soda-AQ high kappa (KHK), (d) kenaf whole soda-AQ low kappa (KLK) and (e) OCC at freeness of 300 mL CSF, (f) unbleached softwood kraft pulp (USWP) at freeness of 400 mL CSF.

## CONCLUSIONS

1. Kenaf pulps and commercial pulps showed different response to beating. In comparison to commercial pulps, kenaf pulps required less refining to achieve the desired freeness.
2. In comparison to commercial pulp, unbeaten core pulp showed significantly higher drainage time, which can affect papermaking speed and production rate. In contrast, beaten bast pulp showed significantly lower drainage time.

3. Beating, which causes fibrillation and improvement fiber bonding, increased all strength properties of bast pulp except for tear strength, which first increased then decreased.
4. At the optimum freeness, USWK and OCC pulps showed the highest and lowest strength properties, except for tear strength, respectively. Again, bast and core pulps showed the highest and lowest tear strength, respectively.
5. Kenaf whole stem pulps (KHK and KLK) gave handsheets with intermediate strength properties between core and bast, and close to USWK.
6. Finally the whole stem pulps (KHK and KLK), due to their good strength properties and avoidance of extra processing steps involved in separation and the extra cost of two pulping lines, were judged to be more suitable for commercialization of kenaf for linerboard production in Malaysia.

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