STRUCTURAL, MECHANICAL AND OPTICAL PROPERTIES OF RECYCLED PAPER BLENDED WITH OIL PALM EMPTY FRUIT BUNCH PULP

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ABSTRACT

The effects of blending oil palm empty fruit bunch (EFB) pulp with recycled papers on the paper properties were studied. The EFB was pulped by the soda-anthraquinone process. Laboratory papers were made by blending the unbleached EFB pulp with old carton board (OCB), copier paper (OCP) and newspaper (ONP) at ratios of 25%, 50% and 75%. The structural, mechanical and optical properties of these papers were measured and compared to unblended recycled papers. The paper properties were considerably affected by incorporation of the EFB pulp. The changes on the properties varied, depending on the particular property, level of pulp incorporation and the type of recycled paper used. ONP has the highest degree of change and OCB has the lowest degree of change. OCB, OCP and ONP have the highest tensile index when incorporated 25%, 75% and 75% of EFB pulp respectively. OCB, OCP and ONP have the highest burst index when incorporated 75% of EFB pulp. OCB, OCP and ONP have the highest tear index when incorporated 25%, 75% and 25% of EFB pulp respectively. OCB, OCP and ONP have the highest folding endurance when incorporated 75% of EFB pulp respectively. The best blend for OCB is 25% of EFB pulp and for OCP and ONP is 75% of EFB pulp. The EFB soda-AQ pulp can be used to enhance the structural and mechanical properties of recycled paper.

Keywords: oil carton board, old copier paper, old newspaper, soda-anthraquinone, unbleached.

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INTRODUCTION

Paper recycling is growing in Malaysia and many of the mills use as much as 100% waste paper in their raw material base. In 1999, all the waste paper collected was used in the country following a ban on its export by the government (Mohd Nor and Mas'ut, 2000). However, Malaysians are not ardent recyclers as only 96 000 t of waste paper are collected a year. Malaysia loses RM 70 million to RM 80 million a year to import 204 000 t of waste paper (The Star, 2001).

Generally, the use of recycled fibre produces paper with poorer mechanical properties due to a decrease in the interfibre bonding (Rushdan, 1998). The recycled pulp must be treated to restore its bonding strength, for which there are six methods possible: mechanical treatment, chemical additives, chemical treatment, fractionation, papermaking process modification and blending with virgin fibre (Minor *et al.*, 1993). Although some mills produce 100% recycled paper, the majority augment their used pulp with some virgin fibre. However, the strength properties of pulp blends are not simply the average of the strength properties of their components. Depending on the nature of the components and the specific property of interest, there may well be positive or negative deviations from the average (Minor *et al.*, 1993).

Pulp can be produced from any plant, woody or non-woody. The African oil palm, *Elaeis guineensis*, is one of the most important plants in Malaysia. It produces palm oil and palm kernel oil, which are widely used in the food and manufacturing industries. Although the oils are important economic

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products for the country, the residues from the palm are largely wasted. One of the most abundant lignocellulosic residues is the EFB, which are the stalk and spikelets of the fruit bunches after removal of the fruits. Malaysia produced 16 million tonnes of EFB in 2000, which were generally used as mulch for oil palms, converted to bunch ash or, as some cases, discarded as waste. Converting this lignocellulosic residue to pulp for paper would be an advantageous way to utilize it as the consumption of paper is increasing rapidly in Malaysia (New Straits Times, 2002). In this work, the effects of blending oil palm EFB with recycled paper on the subsequent paper properties were studied.

EXPERIMENTAL WORK

Five hundred grammes (oven dry) of EFB fibrous strands, provided by Sabutek (M) Sdn Bhd, were pulped by the soda-anthraquinone (soda-AQ) process using a 4-litre rotating digester. The soda-AQ process produces a balanced pulp in yield and chemical composition compared to the soda, kraft and kraft-AQ processes (Rushdan, 2002). The pulping conditions employed were:

- maximum cooking temperature: 170°C;
- time to maximum temperature: 90 min;
- time at maximum temperature: 90 min;
- EFB to liquor ratio: 1:8;
- amount of anthraquinone: 0.1% of EFB dry weight; and
- amount of NaOH: 20% of EFB dry weight.

At the end of digestion, the softened EFB was disintegrated for 5 min in a hydropulper, washed on a screen and screened by a fractionator (Somerville type) with a screen plate of 0.20 mm slits. The pulp was not bleached. Laboratory paper was made by blending the EFB pulp with OCB, OCP and ONP at ratios of 25%, 50% and 75%. The laboratory paper was made by a semi-automatic sheet machine (British Handsheet Machine) according to TAPPI T 205 om-88 *Forming Handsheets for Physical Tests of Pulp* (TAPPI, 1994). The structural, mechanical and optical properties of these papers were measured according to TAPPI T 220 om-88 *Physical Testing of Pulp Handsheets* (TAPPI, 1994) in a controlled temperature and humidity environment as stipulated in TAPPI T 402 om-93 *Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets and Related Products* (TAPPI, 1994) and compared to those of the unblended recycled papers.

RESULTS AND DISCUSSION

Unblended Paper Properties

The properties of the papers made from EFB soda-AQ pulp and recycled paper are shown in *Table 1*. Compared to EFB pulp, the recycled papers had a lower apparent density. The apparent density is an indirect measure of the flexibility of the pulp. A flexible pulp has a higher apparent density as its fibres are more easily compressed into the voids of the sheet. Recycled fibres are stiffer and not so easily compressible (Ellis and Sedlachek, 1993; Minor *et al.*, 1993). The recycled papers also had a lower tensile index, burst index and folding endurance due to some loss in the interfibre bonding (Rushdan, 1998) from collapse of the polysaccharide macromolecules as a result of dehydration (Minor *et al.*, 1993). The degree of fibre bonding in the sheet can be measured by the light-scattering coefficient. ONP and OCP had a higher coefficient than EFB, indicating smaller bonding areas in their recycled papers (Rushdan, 1998).

TABLE 1. PROPERTIES OF PAPERS FROM EMPTY FRUIT BUNCHES (EFB) SODA-AQ PULP AND RECYCLED PAPER

	Oil palm empty fruit bunches (EFB)	Old carton board (OCB)	Old newspaper (ONP)	Old copier paper (OCP)
Apparent density (g cm^{-3})	0.67	0.48	0.41	0.40
Tensile index (Nm g^{-1})	44.95	31.08	21.66	33.10
Burst index (kPa.m^2 g^{-1})	4.14	1.96	1.15	1.53
Tear index (mN.g m^{-2})	6.82	8.56	6.23	7.11
Folding endurance	455.00	12.86	14.00	28.81
Brightness (%)	37.27	26.17	54.02	64.48
TAPPI opacity (%)	95.26	99.38	98.69	98.91
Printing opacity (%)	97.00	99.34	98.59	98.72
Scattering coefficient (m^2 kg^{-1})	33.09	29.42	43.86	43.12
Absorption coefficient (m^2 kg^{-1})	8.53	15.84	7.28	8.13

ONP and OCP had higher brightness and lower light-absorption coefficients than EFB because both were bleached papers. In the bleaching, the lignin and various extractives – the coloured substances - were dissolved or modified, leaving behind only the white cellulose (McGinnis and Shafizadeh, 1980).

Blended Paper Properties

The properties of the papers made from mixtures of the EFB soda-AQ pulp and recycled papers are shown in *Table 2*. The paper properties were greatly affected by the EFB pulp incorporated, with the changes dependent on the particular property, percentage of blending and the type of recycled paper used. The changes as shown in *Table 3* can range from -26.39% to 942%. ONP has the highest degree of change and OCB has the lowest degree of change.

Adding EFB pulp increased the structural and mechanical properties but decreased the optical properties of the recycled papers. ONP produced the

TABLE 2. PROPERTIES OF PAPERS FROM EMPTY FRUIT BUNCHES (EFB) SODA-AQ PULP AND RECYCLED PAPER AFTER BLENDING AT DIFFERENT DEGREES

	Old carton board (OCB)			Old copier paper (OCP)			Old newspaper (ONP)		
EFB (%)	25	50	75	25	50	75	25	50	75
Recycled paper (%)	75	50	25	75	50	25	75	50	25
Apparent density (g cm^{-3})	0.48	0.48	0.54	0.46	0.47	0.45	0.44	0.53	0.56
Tensile index (Nm g^{-1})	36.06	37.40	35.44	43.25	49.65	53.11	28.30	32.49	34.76
Burst index (kPa.m^2 g^{-1})	2.70	2.36	3.03	1.68	2.36	3.01	1.56	2.09	2.98
Tear index (mN.g m^{-2})	8.84	7.50	7.17	7.63	7.30	7.93	6.69	6.40	6.48
Folding endurance	20.00	25.43	28.00	46.19	93.71	160.10	23.00	81.00	146.00
Brightness (%)	28.46	32.71	32.31	59.25	52.06	50.42	49.64	43.62	42.25
TAPPI opacity (%)	99.28	98.68	98.48	98.83	96.11	96.05	98.66	96.89	96.37
Printing opacity (%)	98.84	98.79	98.79	98.61	97.41	97.20	98.57	97.64	97.18
Scattering coefficient (m^2 kg^{-1})	30.01	33.77	32.71	40.21	36.71	35.11	42.37	38.76	39.11
Absorption coefficient (m^2 kg^{-1})	14.19	11.94	11.66	8.72	6.09	7.41	7.73	8.66	7.93

TABLE 3. CHANGES IN THE RECYCLED PAPER PROPERTIES WITH EMPTY FRUIT BUNCHES (EFB) INCORPORATION (%)

	Old carton board (OCB)			Old copier paper (OCP)			Old newspaper (ONP)		
EFB (%)	25	50	75	25	50	75	25	50	75
Recycled paper (%)	75	50	25	75	50	25	75	50	25
Apparent density	0.00%	0.00%	12.50%	15.00%	17.50%	12.50%	7.32%	29.27%	36.59%
Tensile index	16.02%	20.33%	14.03%	30.66%	50.00%	60.45%	30.66%	50.00%	60.48%
Burst index	37.76%	20.41%	54.59%	9.80%	54.25%	96.73%	35.65%	81.74%	159.13%
Tear index	3.27%	-12.38%	-16.24%	7.31%	2.67%	11.53%	7.38%	2.73%	4.01%
Folding endurance	55.52%	97.74%	117.73%	60.33%	225.27%	455.71%	64.29%	478.57%	942.86%
Brightness	8.75%	24.99%	23.46%	-8.11%	-19.26%	-21.81%	-8.11%	-19.25%	-21.79%
TAPPI opacity	-0.10%	-0.70%	-0.91%	-0.08%	-2.83%	-2.89%	-0.03%	-1.82%	-2.35%
Printing opacity	-0.50%	-0.55%	-0.55%	-0.11%	-1.33%	-1.54%	-0.02%	-0.96%	-1.43%
Scattering coefficient	2.01%	14.79%	11.18%	-6.75%	-14.87%	-18.58%	-3.40%	-11.63%	-10.83%
Absorption coefficient	-10.42%	-24.62%	-26.39%	7.26%	-25.09%	-8.86%	6.18%	18.96%	8.93%

biggest changes in the structural and mechanical properties and OCB the lowest changes. Conversely, OCB produced the biggest change in the optical properties and OCP the lowest.

The addition of EFB pulp improved the apparent density, tensile index, burst index and folding endurance of the recycled paper, but had adverse effects on the brightness, TAPPI and print opacity, light-scattering coefficient and light-absorption coefficient. The strength properties of the blended recycled papers were not linearly related to those of the EFB paper (*Table 3* and *Figure 1*).

Density is among the important structural properties of paper (Levlin, 1999). Structural properties deal with the location of furnishes materials within the sheet (Peel, 1999). Apparent density is simply calculated from weight, area and thickness of paper sample. The apparent density of OCB, OCP and ONP was at the maximum after incorporated 75%, 50% and 75% of EFB pulp respectively.

Tensile strength, burst strength, tearing strength and folding endurance are the most important strength or mechanical properties (Levlin, 1999). The maximum changes in the recycled paper mechanical properties with EFB incorporated are shown in *Table 4*.

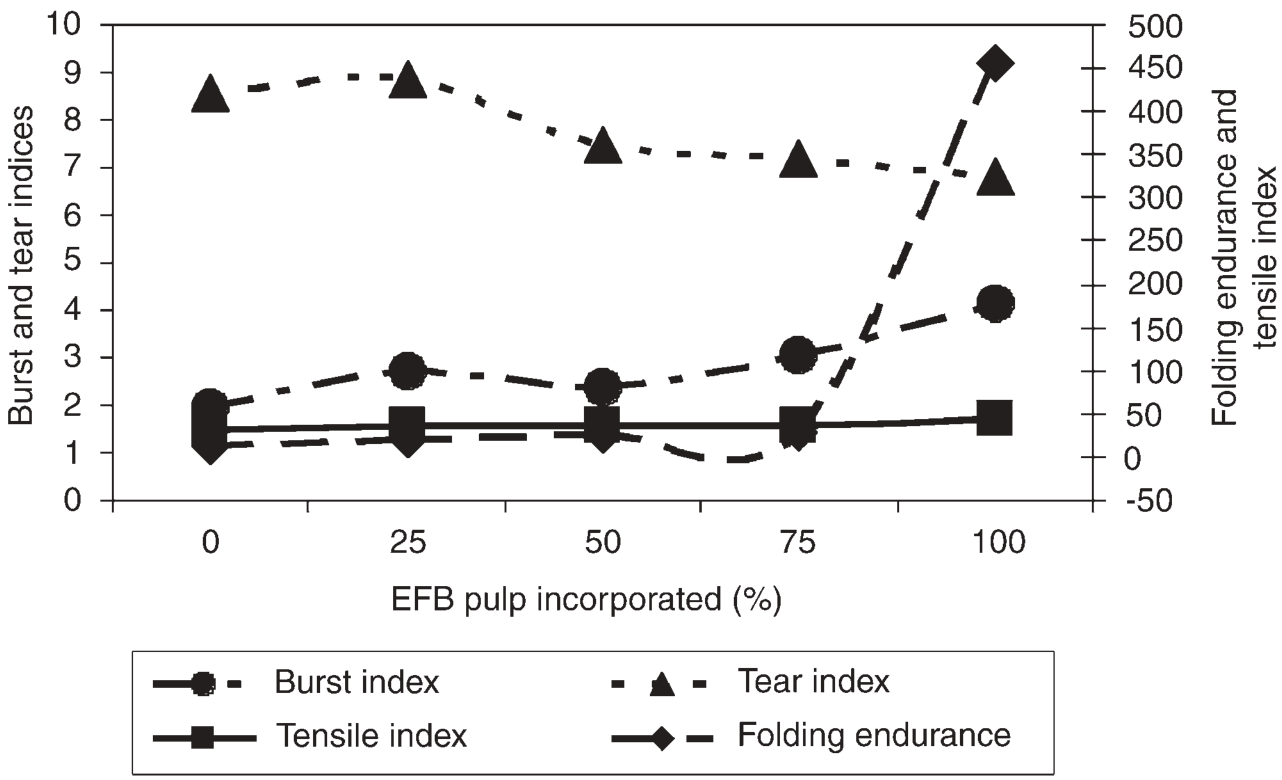

Figure 1. Effects of empty fruit bunches (EFB) pulp incorporation in old carton board (OCB) on the mechanical properties of recycled paper.

TABLE 4. THE MAXIMUM CHANGES IN THE RECYCLED PAPER MECHANICAL PROPERTIES WITH EMPTY FRUT BUNCHES (EFB) INCORPORATION (%)

	Old carton board(OCB)	Old copier paper (OCP)	Old newspaper (ONP)
Tensile index (Nm g $^{-1}$)	25% of EFB	75% of EFB	75% of EFB
Burst index (kPa.m^2 g $^{-1}$)	75% of EFB	75% of EFB	75% of EFB
Tear index (mN.g m $^{-2}$)	25% of EFB	75% of EFB	25% of EFB
Folding endurance	75% of EFB	75% of EFB	75% of EFB

The strength of a paper with randomly oriented fibre is dependent on the strength of the individual fibres and the strength and number of bonds between them (Kallmes and Perez, 1966; Page, 1969; Van den Akker *et al*., 1958). The number of bonds, which is influenced by the fibre flexibility, gives the bonding area. A flexible fibre will have more surface area for bonding. The fibre flexibility and relative bonding area can be determined by the apparent density and light-scattering coefficient of the paper. The apparent density is one of the most significant properties of a paper. It influences almost all the mechanical, physical and electrical properties. The mechanical properties - tensile index, burst index, folding endurance and tear index – increase with the apparent density (*Table 2* and *Figure 2*).

Light is reflected, transmitted, scattered and absorbed by paper. The quantity and quality of interaction of light with paper determined the brightness, opacity scattering and absorption coefficients (Vaarasalo, 1999). The incorporated of EFB pulp has increased the brightness and scattering coefficient of OCB but decreased the brightness and scattering coefficient of OCP and ONP. The incorporated 50% of EFB pulp produced the highest brightness of OCB. The incorporated EFB pulp has increased the absorption coefficient of ONP but decreased the absorption coefficient of OCB and OCP. The incorporated 50% of EFB has increased the highest absorption coefficient of ONP. The light-scattering coefficient is the function of both the internal and interfibre bonded areas as the specific scattering coefficient is proportional to the fibre area (Igmanson and Thode, 1959). The light-scattering coefficient indicates the area of bonding between the component fibres and it is thus generally a measure of the degree of bonding (Clark, 1985). The light-scattering coefficient varies inversely with all the individual mechanical properties (*Table 2* and *Figure 3*).

OCP and ONP are graded as printing paper. The important properties of printing paper are runnability and printability (Suontausta, 1999). The runnability is affected by the paper strength properties. Tensile strength is a very useful property to describe the general strength of paper (Levlin, 1999). OCP and ONP have the highest tensile index when incorporated 75% of EFB pulp. High opacity is necessary in printing paper (Leskela, 1998). All OCP and ONP paper has high opacity (*Table 2*).

OCB is graded as packaging paper and used for rigid packages (Kainulainen and Soderhjelm, 1999). It needs a high strength for protecting the packed product. Since tensile strength describes the general strength of paper, OCB has the highest tensile index when incorporated 25% of EFB pulp.

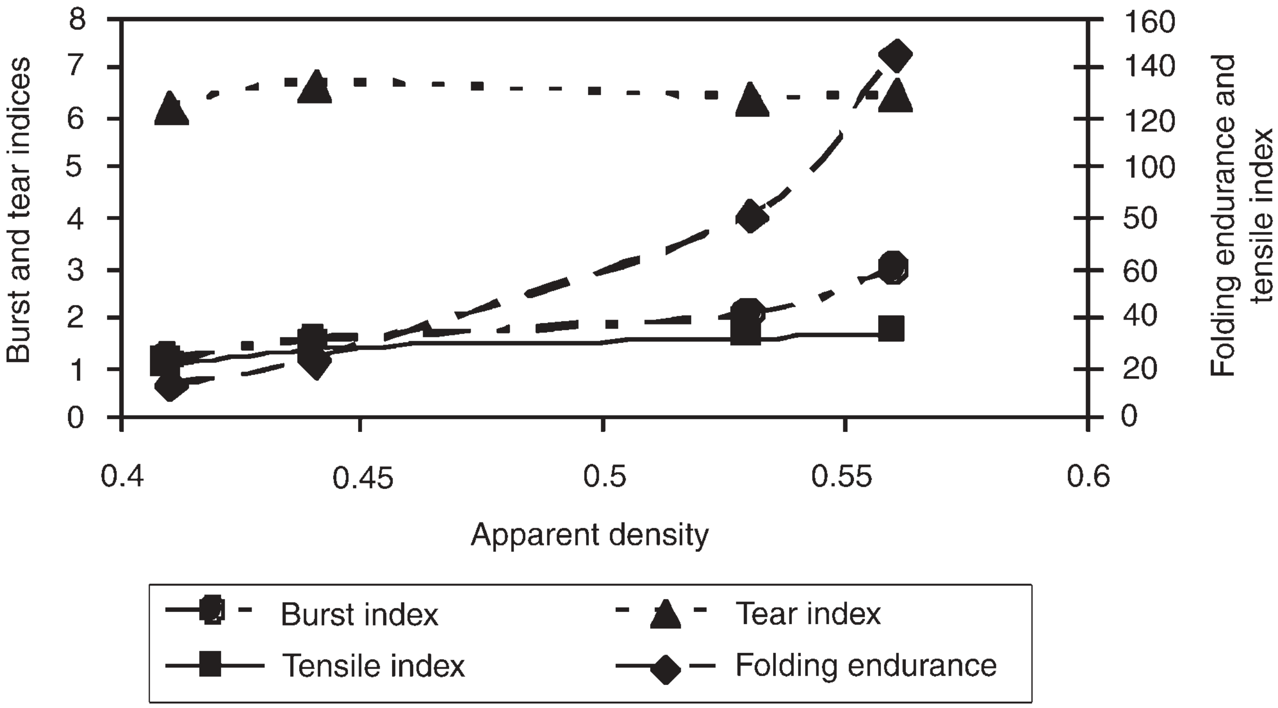

Figure 2. Relationships between apparent density and the strength properties of recycled paper (empty fruit bunches blended with newspaper).

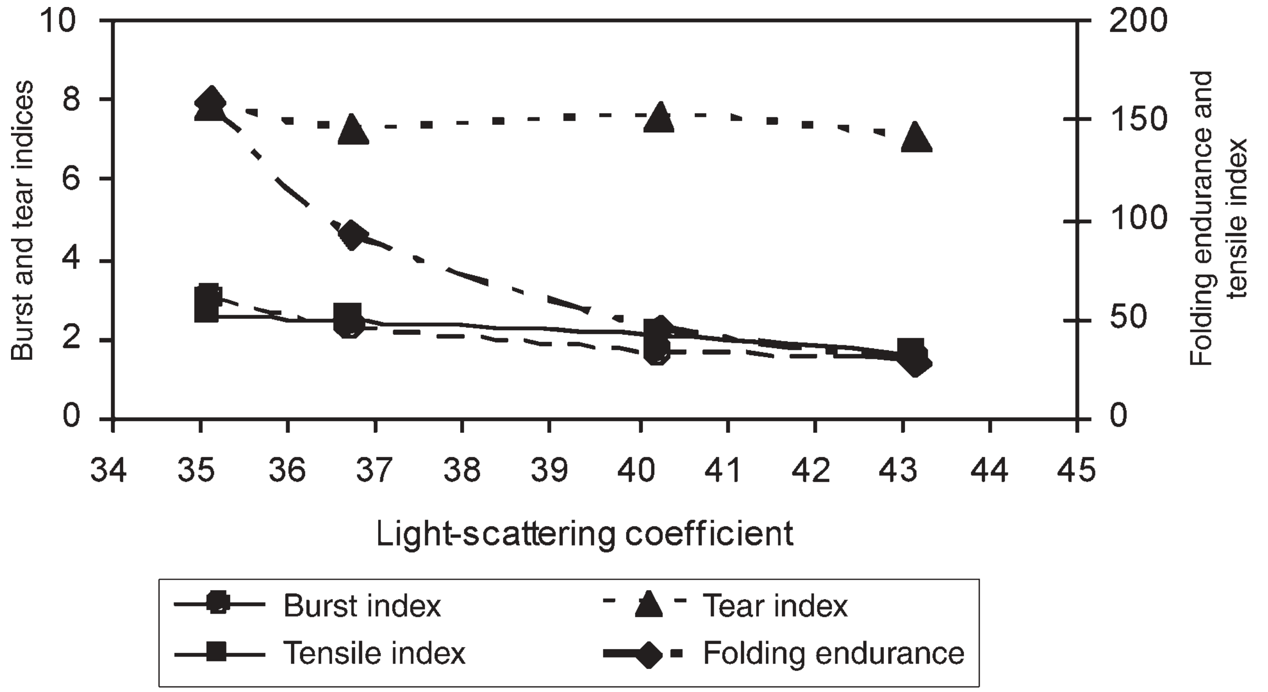

Figure 3. Relationships between the light-scattering coefficient and strength properties of recycled paper (empty fruit bunches blended with copier paper).

CONCLUSION

The properties of recycled paper were affected by the addition of EFB unbleached soda-AQ virgin pulp. The changes on the properties varied, depending on the individual property, percentage of blending and the type of recycled paper used. The blended recycled paper properties were not linearly related to the EFB paper properties. The changes in the paper properties stemmed from the properties of the EFB pulp - its flexibility, potential bonding area and unbleached nature. Increasing the flexibility and bonding area of the EFB pulp increased the mechanical properties of the recycled papers but the lack of bleaching decreased their optical properties. The EFB soda-AQ pulp can be used to enhance the structural and mechanical properties of recycled paper. The amount that needs to be incorporated would depend on the final paper quality required. The best blend for OCB is 25% of EFB pulp and for OCP and ONP is 75% of EFB pulp.

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