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Effect of bleaching on coir fibre pulp and paper properties

(Kesan pelunturan terhadap sifat-sifat pulpa dan kertas sabut kelapa)

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Keywords: coir fibre, unbleached, bleached, paper sheets

Abstract

The utilisation of coir fibre can create economic and environmental advantages. This study was carried out to investigate the influence of bleaching and pulping on the properties of coir fibre pulp and paper. The coir fibre pulp was chemically analysed; pulped by chemical-mechanical pulping (CMP) process and bleached by elementary chlorine free (ECF) process with four stages of chlorine dioxide (D) and alkali extraction (E). Sheets or paper were made from the unbleached and bleached coir fibre pulp. The results showed that in the paper making process, the coconut coir has chemical properties that can be successfully pulped by the CMP and bleached by the ECF processes. The DEDED sequences can be used in bleaching the coir pulps. The bleached pulp produced paper with better tensile index, burst index, tear index, folding endurance as well as brightness properties but has lower opacity compared to the unbleached pulp. The bleaching process also improved the bonding strength of the coir fibre in the paper due to removal of lignin.

Introduction

In the past two decades the Malaysian consumption of paper and board augmented from 374,000 tonnes in 1992 to 1,720,000 tonnes in 2012, an increase of 1,346,000 tonnes within 20 years (FAO 2012). This figure is expected to rise further with the increasing Malaysia population, and improved literacy and quality of life. The country is a net importer of pulp, paper, and paper board, and progressively tends to decrease its dependency. The Malaysian government has identified this particular industry sector as one of the priority areas for investment in the second industrial master plan (FAO 2012). The strategy is to achieve a state of self-sufficiency, to reduce import, and to encourage foreign capital inflow.

The continued high growth in paper consumption will lead to increasing demand for fibre; creating additional pressure on the Malaysia's diminishing forest resources. Meanwhile, the paper industry is also constantly being monitored by the United Nation which has created a programme of sustainable procurement in some developing countries (UNEP 2012). To maintain the growth of the paper industry, the government as well as industry executives have to establish and implement policies and plans that ensure a sustainable fibre supply, including reforestation programme, plantation management recycling and

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development of non-wood raw material (UNEP 2012).

In Malaysia, the possibility of non-wood fibre sources for paper making are agricultural residues from monocotyledons including oil palm empty fruit bunch, frond and trunk, coir fibre, banana trunk, pineapple leaves, corn leaves, rice straw and bagasse. Malaysia is very fortunate to have 150,000 ha of coconut plantation (Muhamad Yuszairi et al. 2012). The coconut is mainly used in producing coconut oil while the coir fibre and shell are by-products or waste of this industry.

Coir is a natural fibre extracted from the husk of coconut and used in products such as floor mats, doormats, brushes, mattresses, etc. Technically, coir is the fibrous material found between the hard, internal shell and the outer coat of a coconut. The brown fibre is obtained by harvesting fully mature coconuts when the nutritious layer surrounding the seed is ready to be processed into copra and desiccated coconut. The fibrous layer of the fruit is then separated from the hard shell manually or using dehusking machine. Coco peat (cocopeat), also known as coir pith, coir fibre pith or coir dust is made from coconut husks and mainly used for soil improvement.

To date, relatively little attention has been given to the use of this coconut waste which can create environmental problem if not disposed properly. The utilisation of coir can create economic and environmental advantages (Abdul Khalil et al. 2006) because the fibres are renewable, non abrasive, cheaper, available in abundance and show less health and safety concern during handling and processing (Zulkifly et al. 2008). These advantages can be of great potential in converting the coir fibres into pulp and paper products.

The characteristic quality of the paper produced depends on the chemical properties, pulping process, bleaching process and papermaking process. The chemical properties will affect the chemical reaction and consumption during pulping and bleaching processes (Dence 1996). There are various methods of pulping process such as chemical, mechanical and chemi-mechanical or hybrid. Furthermore, there are also three methods of bleaching the coir fibre i.e. the conventional method using chlorine gas, the elementary chlorine free (ECF) method and the total chlorine free (TCF) method (Dence 1996). The papermaking process also depends on what the final products will be used for such as writing, printing, packaging and sanitary (Smook 2002).

Thus the objective of this study was to investigate the suitability of the Malaysian coir fibre for producing bleached chemi-mechanical paper.

Materials and methods

Sample preparation

The coir fibre was purchased from a local coir manufacturer in Bagan Datoh, Perak. A long strand of untreated coir fibre was cut into 3 – 5 cm lengths using a locally made drum cutter model SY-50. The length of the fibre should not be less than 3 cm because it could affect the yield of pulp during the pulping process (Mehdi et al. 2009)

The coconut coir was converted into air-dry wood meal in very fine particles form. The coconut coir was ground into fine particles using a Wiley Laboratory Mill and screened. Particles that passed through BS 40 mesh (425 μm) and retained on BS 60 mesh (250 μm) sieve screens were collected and used for determining the chemical components as described by the Technical Association of the Pulp and Paper Industry (TAPPI 1997, 2002).

Chemical analysis

Alcohol-acetone solubility This analysis was carried out according to TAPPI T 204 cm-97 test method (TAPPI 1997) with minor modification. Ethanol-acetone was used as the solvent. A sample of 5 g ground fibre was weighed in a pre-tarred extraction thimble which was placed into the soxhlet barrel at the top of the thimble

above the siphoning tube of the extractor. Simultaneously, the round bottom flask was filled with 250 ml of ethanol-acetone (1:2) and the ground fibre was extracted for 6 h, allowing reflux and siphoning from the soxhlet at least four times per hour.

At the end of the extraction process, the heat was shut off to allow the solvent to cease boiling. The thimble was removed and the extracted specimen was allowed to be air-dried overnight. Subsequently, the solvent containing the extract was rotated and allowed to evaporate. The extraction flasks containing the extract were dried in the oven at 105 ± 3 ºC to reach a constant weight. The flasks were removed from the oven and allowed to cool in desiccators for about 20 min and the weight was recorded. The content of the extract was determined by measuring the weight loss after extraction on dried weight basis (TAPPI 1997).

1% NaOH solubility The 1% NaOH solubility test was carried out according to TAPPI T 212 om-02 test method (TAPPI 2002). A sample of 2 g of ground fibre was placed in the 200 ml beaker, then 100 ml of NaOH solution was added and the mixture was stirred with a glass rod. The beaker was placed in a water bath maintained at 97 – 100 ºC for 60 min. During this period, the specimen was stirred about 5 sec at 10, 15 and 25 min after placing in the bath. After 60 min, the materials were transferred to a tarred filtering crucible and washed using 100 ml of hot distilled water. Then 25 ml of 10% acetic acid was added and left for 1 min before filtering. This stage was repeated with a second 25 ml of 10% acetic acid. The materials were finally washed with hot distilled water until they were free of the acid. The crucible was dried in an oven at 105 ± 3 ºC to reach a constant weight. The 1% NaOH extract percentage, S, was calculated using the formula:

$$S = \frac{(A - B)}{A} \times 100$$

A = Oven-dried weight of test specimen before extraction, g
B = Oven-dried weight of test specimen after extraction, g

Hot-water extract solubility A sample of 10 g of air-dried 60 mesh size coir fibres were weighed and transferred into a flask and 100 ml of hot distilled water was added (TAPPI 1999a). The flask was then placed in a boiling water bath for 3 h. The contents of the flask were transferred to a tarred filtering crucible and the liquid removed by suction. The extract was washed with 200 ml hot distilled water (TAPPI 1999a) and finally, the content of the hot water extract was calculated using the formula:

$$\text{Hot water extract content} = \frac{(A - B)}{A} \times 100$$

A = Oven-dried weight of test specimen before extraction, g
B = Oven-dried weight of test specimen after extraction, g

Ash content The ash content was determined according to TAPPI T 211 om-93 (TAPPI 1993). The empty crucible was ignited in a muffle furnace at 525 ± 25 ºC for 30 – 60 min. After ignition, the crucible was cooled slightly, placed in desiccators and weighted. The specimen was filled into the crucible and covered with a lid. The specimen was then gently carbonised on the hearth of the furnace. The lid was removed from the crucible when the furnace temperature reached about 100 ºC. The temperature was raised to 525 ºC slowly to avoid the specimen from carbonised without flaming. When the specimen was completely combusted as indicated by the absence of black particles, the crucible was removed from the furnace, and the lid replaced. The crucible was allowed to cool in desiccators and weighed. The ignition and weighing were repeated until the weight of the ash became constant.

Acid insoluble lignin Acid insoluble lignin or Klason lignin was determined according to TAPPI T 222 om-02 (TAPPI 2002). First, 1 g of oven-dried extract-free specimen was put into a 30 ml beaker, then 15 ml cold (10 – 15 ºC) 72% sulfuric acid (H_2SO_4) was slowly added with constant stirring to ensure the specimen and acid were thoroughly mixed. During this operation, the mixture was frequently stirred and maintained in a water bath at 20 ± 1 ºC for 2 h. After that, the sulphuric acid strength was brought down to 3% by adding 560 ml of hot distilled water. The solution was then boiled for 4 h, maintaining a constant value (575 ml) by frequent addition of hot distilled water. Subsequently, the insoluble lignin was allowed to settle, and it was then filtered in a weighed filtering crucible. The lignin-containing crucibles were then oven-dried to a constant mass. The Klason lignin content was calculated as using the formula:

$$\text{Klason Lignin, \%} = \frac{100A}{W}$$

A = Weight of Klason lignin, g
W = Oven-dried weight of test specimen, g

Holocellulose, alpha-cellulose and hemicellulose determinations The holocellulose content was carried out according to modifications of the method of Wise et al. (1946). A sample of 2 g oven-dried extract-free specimen was weighed in a 250 ml Erlenmeyer flask. A volume of 100 ml of distilled water was added, followed by 1.5 g sodium chlorite ($NaClO_2$) and 5 ml of 10% acetic acid. A 25-ml Erlenmeyer flask was inserted into the neck of 250-ml Erlenmeyer flask and was then placed into a water bath at 70 ºC. The flask was heated for 30 min with frequent stirring (Wise et al. 1946). Then, 5 ml of 10% acetic acid was added and an additional of 1.5 g $NaClO_2$ was added after 30 min. The alternate additions of acetic acid and $NaClO_2$ were continued at 30 min intervals until 6 g of $NaClO_2$ had been added, after which, the flask was further heated for 30 min after the last addition of $NaClO_2$. The specimen was then allowed to cool until it was below 10 ºC and filtered in a weighed filtering crucible by washing with iced-distilled water. Subsequently, it was washed with acetone and allowed to be air-dried. Finally, the residue was transferred into desiccators and weighed at daily intervals until the specimen reached a constant weight. The operation due to toxicity of chlorine dioxin was carried out in a designated area of the well-ventilated cupboard (Wise et al. 1946).

Alpha-cellulose was determined according to TAPPI T 203 cm-99 (TAPPI 1999b). The holocelluose-containing crucible was placed in a Syracuse watch glass, which contained water to a depth of 1 cm and 3 ml of 17.5% NaOH was added to each crucible. After 5 min, additional of 17.5% NaOH (3 ml) was added. The contents were allowed to stand for 35 min, a total of 42 min contact time. After washing with 60 ml of distilled water, 5 ml of 10% acetic acid was added and 5 min later, the alpha-cellulose was washed with distilled water (60 ml), and then finally with acetone (20 ml). After washing, the sample was oven-dried to constant weight, and the alpha cellulose content calculated based on oven-dried weight. The hemicellulose content was calculated by the weight difference between the two, subtracting the weight of alpha-cellulose from that of holocellulose (TAPPI 1999b).

Pentosans About 1 g of accurately weighed oven-dried sample was placed in a distilling flask, together with 100 ml of 12% hydrochloric acid. Distillation was carried out so as to distill 30 ml in 10 min and continued until the distillate amounted to 360 ml. Then, 40 ml of phloroglucinol solution was added to the distillate. After allowing this to stand for 16 h, the precipitate was collected on a tarred fritted-glass crucible and washed with 150 ml of water, dried for 4 h at 105 °C, cooled and

weighed with the crucible in a stoppered weighing bottle. The precipitate was dissolved in hot 95% ethanol and the residue was weighed also. Pentosan was calculated from the weight of the residue. Methyl-pentosan was calculated from the weight of soluble phloroglucide. The sum of these amounts was expressed as total pentosan (Savard et al. 1954).

Chemi-mechanical pulping (CMP) process

About 1 kg of cut coir fibre (oven-dry weight) was soaked for 18 h in a 5% solution of sodium hydroxide (NaOH) at room temperature before being heated to a temperature of 60 ºC in a rotary digester for 1 h. The liquor to fibre ratio is 8:1. After impregnation, the coir fibre was washed to remove all NaOH from the surface. The pre-treated coir fibre was fed into 12-inch single disc atmospheric laboratory refiner (Sprout Waldron) in a two-stage operation. The primary stage was operated at a load between 18 and 20 amperes at an inlet consistency of 10% and the plate (D2A507, Sprout Waldron) clearance set at 0.89 mm. The collected stocks were refined in a secondary stage that was operated with an inlet consistency of 7%, and with the refiner plate clearance set at 0.13 mm. The pulp obtained was thoroughly washed and screened by the Sommerville fractionator with a screen plate of 0.20 mm slits. The screened pulp was spin to discharge water and disintegrated for 5 min in a mixer (Rushdan et al. 2008).

Bleaching process of coir fibre pulp

The bleaching process was carried out using the DEDED (chlorine dioxide – extraction – chlorine dioxide – extraction – chlorine dioxide) sequence to produce paper with more than 80% brightness, suitable for writing and printing (Mahmudin et al. 2008). The process was conducted by mixing unbleached pulps with bleaching agent at five different stages as stated in *Table 1*. The pulps were washed thoroughly with water between bleaching stages. The pulp brightness was measured according to TAPPI Standard method (TAPPI 1992).

Determination of coir fibre pulp properties

The total pulp yield was calculated as the sum of the screened pulp yields and screen rejects. Pulp properties like kappa number was determined according to the method of TAPPI T 236 (TAPPI 1985). It measures the quantity of lignin left in the pulp. The determination of viscosity was carried out according to TAPPI T 230 om-89 (TAPPI 1989). This method determines the viscosity of 0.5% cellulose solution, using 0.5 M cupri-ethylene-diamine (CED) as solvent and a capillary-type viscometer. It is important to detect the viscosity of unbleached or bleached pulps.

Papermaking

Paper or handsheets were made according to TAPPI T 205 om-88 method (TAPPI 1988a). The paper was made by mixing the pulp with water in a British handsheet

Table 1. The DEDED sequence for bleaching the coir fibre pulps

Treatment	Pulp consistency (%)	Temp. (°C)	Reaction time (m)	Chemicals (%)
First stage (D)	10	70	120	2
Second stage (E)	10	60	10	1
Third stage (D)	10	70	90	2
Fourth stage (E)	10	70	10	1
Fifth stage (D)	10	70	90	1

D = Chlorine dioxide + acetic acid (3%); E = Natrium hydroxide (NaOH)

former, put on the screen and pressed at 345 kPa (50 psi) for 5 min and dried in the stainless steel stacker for 24 h or longer. The handsheets were cut and tested according to TAPPI T 220 om-88 (TAPPI 1988b). All handsheet properties were tested in a controlled temperature and humidity condition as stipulated in TAPPI T 402 om-93 (TAPPI 1993). The paper properties were analysed as follows:

Apparent density The apparent density is the weight of paper per unit area. This can be expressed as the weight in grams per square meter (GSM or g/m^2).

Burst index This test is designed to measure the maximum bursting strength of the paper between 50 kPa and 1200 kPa with maximum thickness of 0.6 mm. To test the bursting strength, a burst tester was used according to TAPPI Standard T 403 om-97 (TAPPI 1997).

After cutting eight specimens from the paper handsheets, the smoother (glazed) side of each sheet was clamped towards the diaphragm. Hydrostatic pressure was applied at the standard rate of increase until the specimen ruptured. The pressure at rupture (B.kPa) was read from the instrument and burst index was calculated using the following formula (TAPPI 1997):

$$\text{Burst index, kPa.m}^2\text{/g} = \frac{B}{G}$$

B = Bursting strength, kPa
G = Grammage, g/m^2

Folding The folding test is conducted according to TAPPI (1996) using a mechanical folder which has an oscillating folding head placed in the position of the zero folds. At the top of the spring loaded plunger, a weight equivalent to the tension desired on the specimen (size of 15 mm width and 120 mm length) was attached. The plunger was clamped in position when depressed under the load by tightening the plunger lock screw. The paper specimen was then firmly clamped in the jaws of the machine with the surface of the specimen lying wholly within one plane and not touching the oscillating jaw mounting plate. The specimen was handled by the ends making sure the region to be folded was not touched. The specified tension was then applied to the test strip by removing the weight and loosening the plunger lock screw. The paper strip was folded at a uniform rate of 175 ± 25 double folds per minute until it is severed at the crease. The number of double folds required to severe the specimen was recorded. Eight tests were conducted in each of the principal directions (TAPPI 1996).

Tear index The standardised 4-ply Elmendorf (out-of-plane) tear has been used in the industry for many decades according to TAPPI Standard T 414 om-98 (TAPPI 1998). This method uses an L&W Tearing Tester to measure the force required to tear multiple plies of paper, perpendicular to the plane of the paper, through a specified distance, after the tear has been initiated by a standard cut.

After cutting each sample to size of 50 mm long by 62 mm wide, 4 cut specimens were sandwiched and centred in the clamps. An initial standard cut was made at a distance of 20 mm from the bottom edge of the samples. The tearing distance was set at 43 ± 0.2 mm. The results are shown in 'mN' units per specimen. The calculation of the tear index was as follows (TAPPI 1998):

$$\text{Tear index, Nm}^2\text{/g} = \frac{Te}{G}$$

T_e = Tear strength, mN
G = Grammage, g/m^2

Tensile index The tensile properties of the paper are tested with a testing machine that provides a constant rate of elongation, as specified in the TAPPI Standard T 494 om-01 (TAPPI 2001).The specified numbers of 8 handsheets were kept in the conditioned

room for 24 h or longer. After preparing the samples with size of 100 mm long by 15 mm wide, the testing machine was calibrated and the following parameters were set: crosshead speed = 12 mm per min, test span = 100 mm and sample width = 15 mm.

As specified in the various TAPPI test methods used, testing of tensile strength is conducted in a conditioned room maintained at temperature of 23 ± 1 °C and RH of 50 ± 2.0%. Each specimen for tensile strength testing was clamped in the jaws of the tensile test instrument and the automatic test sequence started. The tensile strength data were displayed automatically by the instrument. Tensile index was calculated using the following formula (TAPPI 2001):

$$\text{Tensile index, Nm/g} = \frac{\text{T x 1000}}{\text{G}}$$

T = Tensile strength, N
G = Grammage, g/m^2

Opacity Opacity is the ratio measurement of the reflected light from each paper covered by a black cover with 5% reflected light in comparison with the specimen covered by a bulky paper. Opacity is measured by the Spectrophotometer Color Touch 2 (Model ISO, Technidyne Corporation USA) according to TAPPI Standard T 425 om-01 method (TAPPI 2001). The opacity value is calculated in % (TAPPI 2001).

Brightness Brightness is the term used in the industry to evaluate the value factor of reflected blue light on the 457 nm wave. The Spectrophotometer Color Touch 2 was used to measure brightness according to TAPPI Standard T 452 om-02 (TAPPI 2002). Eight handsheets were arranged in the same direction with the smooth surface on top and readings were recorded. The handsheet at the top was then placed at the bottom and the test was repeated until eight readings were recorded. Brightness unit is calculated in percentage (TAPPI 2002).

Experimental design and statistical analysis
The experiment was conducted in a completely randomised design (CRD) with two treatments, namely bleached and unbleached pulp and the number of observation taken for each parameter was 8 (n = 8). All data were analysed using Statistical Analysis Software (SAS 9.1) to study the effect of bleaching on pulp and paper properties of coir fibre. The differences among means were separated according to Duncan Multiple Range Test at $p < 0.05$ level.

Results and discussion

Chemical analysis
Information on the chemical constituent is important in deciding techno-commercial suitability as well as the method of pulping, even though any lignocellulosic material can be pulped with suitable methods. The results of chemical analysis on coconut coir fibre and comparison to *Acacia mangium* and oil palm empty fruit bunch (EFB) are given in *Table 2*. *Acasia mangium* and EFB are used commercially for producing pulp and paper in Malaysia by Sabah Forest Industry (SFI) and Sea Pacific Paper Technology (SPPT) respectively.

The results indicated that coir fibre had highest ash, alkali solubility and lignin but low in holocellulose, α-cellulose, hot water solubility and silica compared to *A. mangium* and EFB (*Table 2*). The 1% NaOH solubility is important in assessing the benefit of coir fibre in respect to its decay. The values ranging from 10 – 30% is normally considered adequate for further investigation (Sanajy et al. 2008). The 1% NaOH solubility was 17.3% which indicated that the coir fibre was a suitable raw material for pulp and paper making (Sanajy et al. 2008). As illustrated in *Table 2*, it was anticipated that coir fibre would not face difficulty in pulping by the chemical or chemi-mechanical pulping processes since it has similar cellulose content (70%) with low lignin (32%) than a coniferous wood

Table 2. Chemical components of coir (%) as compared to *Acacia mangium* (Mazlan et al. 2005) and oil palm empty fruit bunch (EFB) (Rushdan 2002)

Sample	Ash	Extractive	Holocellulose	α-cellulose	Alkali	Hot water	Lignin	Pentosan	Silica
Coir	2.1	2.7	70.5	37.4	17.3	2.6	32.1	22.0	0.5
Acacia mangium	0.2	na	77.5	50.3	11.8	4.1	23.5	18.0	na
EFB	1.3	3.7	82.4	62.9	14.5	7.5	18.8	27.3	0.9

na = Not available

Table 3. Coir fibre pulp properties

Type of pulp	Kappa number	Viscosity (cP)	Yield (%)
Unbleached pulp	86.87a	6.20a	78.43a
Bleached pulp	44.35b	3.49b	77.64a

Means with the same letter within the same column are not significantly different at 5%

Table 4. Strength and optical properties of coir fibre paper

Apparent density (g/cm^3)	Tensile index (Nm/g)	Burst index ($kPa.m^2$)	Tear index (mNm^2/g)	Folding (no.)	Opacity (%)	Brightness (%)
UB* 0.37a	18.33a	1.85a	7.05a	8.57a	99.60a	16.28a
B** 0.44b	30.56b	3.35b	11.78b	67.43b	85.46b	82.87b

UB* = Unbleached paper; B** = Bleached paper
Means with the same letter within the same column are not significantly different at 5%

(cellulose 65 – 70% and lignin 26 – 34%) (Moore 1996).

Pulp properties

After bleaching there was a significant drop of 48.95% in Kappa number from 86.87 of unbleached pulp to 44.35 of bleached pulp (*Table 3*). The Kappa number is an indication of the residual lignin content of the pulp. The percentage of Klason lignin approximately calculated as kappa number × 0.13. The Klason lignin content in unbleached and bleached pulps is 11.29% and 5.77% respectively. The decreasing Kappa number could be due to the removal of lignin in the bleached pulp during the bleaching process.

The same trend was also observed in the viscosity of the unbleached pulp solution. After bleaching there was a significant decrease of 43.71% of viscosity in the bleached pulp (down from 6.20 cP in unbleached pulp to 3.49 cP in bleached pulp (*Table 3*). The average of polymerisation degree of pulp was measured by the viscosity and it indicated the degree of carbohydrate degradation during pulping and bleaching (MacLeod et al. 1994). The results showed that the degradation of carbohydrate could contribute to viscosity drop in the bleached pulp solution.

The bleaching process did not affect the yield of unbleached and bleached coir fibre pulp at 78.43% and 77.64% respectively. The slight decrease in pulp yield after bleaching was due to the delignification and carbohydrate degradation during pulping and bleaching process but the effect was not significant (*Table 3*). The yield of hardwood processed with chemi-mechanical pulping was 85 – 90% (Smook 2002) while the yield of *A. mangium* and

EFB was 83% (Law and Wan Rosli 2000) and 75% (Mohd Nor 1998) respectively. The coir chemi-mechanical pulp yield was lower than hardwood but higher than EFB.

Paper properties

The bleaching of pulp improved the apparent density, tensile index, burst index, folding endurance and brightness of the coir fibre paper significantly, but had adverse effects on the paper opacity (*Table 4*). The removal of lignin during the bleaching process probably increased the bonding strength due to the exposure of cellulose and hemicelluloses which contain hydroxyl and carboxyl acid groups that contribute to the interfibre bonding (Retulainen et al. 1998).

The apparent density is among the important structural properties of paper which influences almost all the mechanical, physical and electrical properties (Levlin 1999). It is calculated based on the weight, area and thickness of paper sample. The mechanical properties (tensile index, burst index, folding endurance and tear index) increase with the apparent density. The apparent density of bleached paper had significantly higher value compared to unbleached paper and significantly influenced all the properties of the paper produced (*Table 4*).

Tensile strength, burst strength, tearing strength and folding endurance are the most important strength or mechanical properties of paper (Levlin 1999). 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 (Amal and Samar 2012). 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 coir fibre bleached pulp increased the paper brightness but decreased the paper opacity. Bleached pulp produced significant higher percentage of paper brightness (82.87%) compared to unbleached paper (16.28%) (*Table 4*). The significant increase in the paper brightness was probably due to the destruction of lignin derivatives during the pulping and bleaching stages (Histed et al. 1996). A light-absorbing substance in the pulp which is derived from the lignin of the absorbing constituents allows the paper to reflect more light. These light-absorbing substances are oxidised and reduced to make them soluble in aqueous solution in order to remove them from the pulp (Histed et al. 1996). Thus, the multistage bleaching process of the pulp provide much greater improvement in brightness. Interstage washing which removes dissolved impurities, is partially responsible for improvement in the extent and efficiency of bleaching. Meanwhile, the opacity of unbleached pulp showed significant higher value (99.60%) than pulp that has been bleached (85.46%) (*Table 4*). It is clear that the unbleached pulp is able to absorb more light which might be influenced by the higher lignin content in the pulp.

Conclusion

This study showed that coir fibre has chemical properties that can be exploited for successful paper production. The DEDED sequences can be used in the bleaching process of coir pulps. The results showed that bleaching of coir fibre pulp produced paper with better tensile index, burst index, tear index, folding endurance as well as brightness properties with lower opacity than the unbleached pulp. This was mainly due to the removal of the lignin in the coir fibre during the bleaching process which increased the bonding strength of the coir fibre paper. During the bleaching process, exposure of cellulose and hemicellulose which contain hydroxyl and carboxyl acid groups also contributed to the interfibre bonding of the coir fibre which further increased the bonding strength of the paper.

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References

Amal, H.A.K. and Samar, H.M. (2012). Physical and mechanical properties of unbleached and bleached bagasse sheets after exposure to ultra violet light. *Applied Science Research* 4(3): 1363 – 1371

Abdul Khalil, H.P.S., Alwani, S.M. and Mohd Omar, A.K. (2006). Chemical composition, anatomy, lignin distribution, and cell wall structure of Malaysian plant waste fibers. *BioResources* 1(2): 220 – 232

Dence, C.W. (1996). Reaction principles in pulp bleaching. In: *Pulp bleaching: principles and practices* (Dence, C.W. and Reeve, D.W., eds.), p. 113 – 124. Atlanta: TAPPI Press

FAO (2012). Paper and paperboard production and consumption for Malaysia. Retrieved on 8 May 2013 from http://www.fao.org.

Histed, J.A., Sandel Jr., L.F. and Hurst, M.M. (1996). Hypochlorite and hypochlorous acid bleaching. In: *Pulp bleaching: principles and practices*, (Dence, C.W. and Reeve, D.W., eds.), p. 395 – 410. Atlanta: TAPPI Press

Law, K.N. and Wan Rosli, W.D. (2000). CMP and CTMP of a fast-growing tropical wood: *Acacia mangium*. *TAPPI Journal* 83(7): 901 – 917

Levlin, J. (1999). General physical properties of paper and board. In: *Papermaking science and technology: Pulp and paper testing*, (Levlin, J. and Soderhjelm, L., eds.), p. 136 – 161. Helsinki, Finland: Fapet Oy

MacLeod, J.M., Kingsland, K.A., O'Hagan, T.J., Thomas, B.C., McPhee, F.J., Tristram, R.W. and Kowalska, R.E. (1994). Pulp strength delivery along complete kraft pulp fibre lines. *1994 Pulping Conference: Proceedings*, TAPPI, Atlanta, p. 183 – 192

Mahmudin, S., Latifah, J., Mohd Nor, M.Y., Rushdan, I., Sharmiza, A. and Ainun, Z.M.A. (2008). Feasibility study of utilizing kenaf fibre as a potential material for pulp and paper manufacturing. In: *Highlights of FRIM Non-MOSTI Projects*, (Ho, Y.F. and Sarifah, K.A., eds.), p. 60 – 64. Kepong: FRIM

Mazlan, I., Wan Rosli, W.D. and Rushdan, I. (2005). Effect of kraft pulping variables on pulp and paper properties of *Acacia mangium*. In: *Lignocellulose: Materials for the future from tropics*, (Tanaka, R. and Cheng, L.H, eds.), p 86 – 89. *JIRCAS Working Report No. 39*. Japan: JIRCAS

Mehdi, J., Jalaludin, H., Alireza, S., Manjusri, M. and Kristiina, O. (2009). Chemical composition, crystallinity and thermal degradation of bleached and unbleached kenaf bast pulp and nanofibers. *BioResources* 4(2): 626 – 639

Mohd Nor, M.Y. (1998). Properties of chemi-mechanical pulp from oil palm empty fruit bunch fibres. Paper presented at the Malaysian Science & Technology Congress '98. 30 – 31 Oct. 1998, Johor Bahru

Moore, G. (1996). *Non-wood fibre applications in paper making*. Surrey, United Kingdom: Pira Int.

Muhamad Yuszairi, A., Muhammad Hakim, S., Siti Nurbaya, M. and Noorasmareena, C.A.L. (2012). The status of coconut plantation in malaysia. Retrieved on 10 May 2013 from http://coconutpeople2.blogspot.com/2012/06/report-status-of-coconut-plantation-in.html

Retulainen, E., Niskanen, K. and Nilsen, N. (1998). Fibres and bonds. *Papermaking Science and Technology* 16: 54 – 87

Rushdan, I. (2002). Chemical composition of alkaline pulps from oil palm empty fruit bunches. *Oil Palm Bull*. 44: 19 – 24

Rushdan, I., Mahmudin, S., Sharmiza, A., Latifah, J., Mohd. Nor, M.Y. and Ainun Zuriyati, M. (2008). Pulping of *Endospermum malaccense*: Thinning from a forest plantation. In: *Conference on Forestry & Forest Products Research 2007,* (Gan, K.S., Lim, H.F. and Mohd. Nor, M.Y., eds.), p. 395 – 406. Kepong: FRIM

Sanajy, N., Chhetri, R.B., Pande, P.K. and Geetika, N. (2008). Evaluation of parthenium for pulp and paper making. *Indian Journal of Weed Science* 40 (3 and 4): 188 – 191

Savard, J., Besson, A. and Morize, S. (1954). *Chemical analysis of tropical timber*. Publication No. 5, 191 p. Nogent-sur-Marne, France: Centre Technique Forestier Tropical

Smook. G.A. (2002). *Handbook for pulp and paper technologists*. 3rd edition. Vancouver, Canada: Angus Wilde Publications Inc.

TAPPI (1985). Test Methods T 236 cm-85. Atlanta, GA: Technical Association of the Pulp and Paper Industry

—— (1988a). Test Methods T 205 om-88. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (1988b). Test Methods T 220 om-88. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (1989). Test Methods T 230 om-89. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (1992). Test Methods T 452 om-92. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (1993). Test Methods T 211 om-93 and T 402 om-93. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (1996). Test Methods T 511 om-96. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (1997). Test Methods T 204 om-97 and T 403 om-97. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (1998). Test Methods T 414 om-98. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (1999a). Test Methods T 207 om-99. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (1999b). Test Methods T 203 cm-99. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (2001). Test Methods T 425 om-01 and T 494 om-01. Atlanta, GA: Technical Association of the Pulp and Paper Industry
—— (2002). Test Methods T 212 om-02, T 222 om-02, T 257 om-02 and T 452 om-02. Atlanta, GA: Technical Association of the Pulp and Paper Industry

UNEP (2012). *Resource efficiency in UNEP annual report 2012*. 99 p. Paris, France: United Nations Environment Programme Industry and Environment

Wise, L.E., Murphy, M. and D'Addieco, A.A. (1946). Chlorite holocellulose, its fractionation and bearing on summative wood analysis and studies on the hemicelluloses. *Pap. Trade J.* 122(2): 35 – 43

Zulkifli, R., Mohd Nor, M.J., Mat Tahir, M.F., Ismail, A.R.J. and Nuawi, M.Z. (2008). Acoustic properties of multi-layer coir fibres sound absorption panel. *Appl Sc.* 8(20): 3709 – 3714

Abstrak

Penggunaan sabut kelapa berupaya memberi faedah kepada ekonomi dan alam sekitar. Kajian ini dijalankan bagi mengkaji kesan pelunturan dan pempulpaan terhadap sifat-sifat pulpa dan kertas sabut kelapa. Pulpa sabut kelapa telah dianalisis kandungan kimianya, pempulpaan dengan proses kimia-mekanikal (CMP) dan diluntur dengan proses bebas asas klorin (ECF) dengan empat peringkat klorin dioksida (D) dan pengekstrakan alkali (E). Helaian kertas telah dibuat daripada pulpa sabut kelapa yang diluntur dan tidak diluntur. Keputusan menunjukkan sabut kelapa mempunyai sifat-sifat kimia yang berupaya untuk proses pempulpaan CMP dan pelunturan dengan proses ECF. Turutan DEDED boleh digunakan dalam proses pelunturan pulpa sabut kelapa. Pulpa terluntur menghasilkan kertas yang mempunyai indeks tegangan, indeks pecahan, indeks koyakan, lipatan dan kecerahan lebih baik tetapi rendah pada sifat kelegapan berbanding dengan pulpa yang tidak terluntur. Proses pelunturan juga meningkatkan kekuatan ikatan kertas sabut kelapa disebabkan kehilangan lignin.

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