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EFFECTS OF BEATING ON THE CHARACTERISTICS OF MALAYSIAN DURIAN (*DURIO ZIBETHINUS MURR.*) RIND CHEMI-MECHANICAL (CMP) PULP AND PAPER

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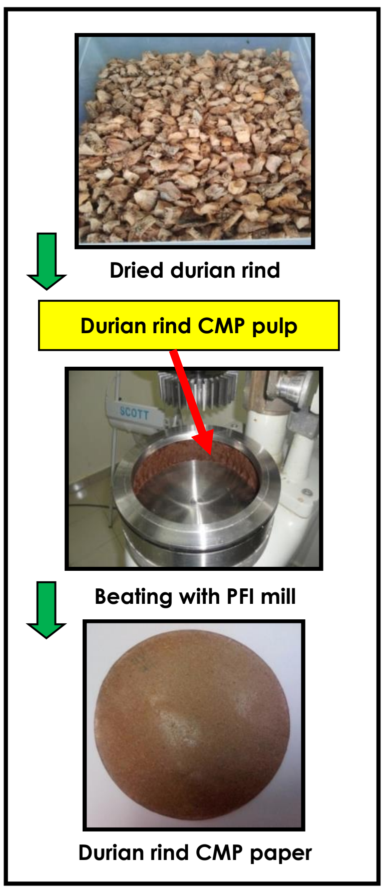
Graphical abstract



Abstract

The effects of beating on the characteristics of pulp and paper derived from durian rind under chemi-mechanical pulping (CMP) method were investigated. All process and characteristic tests were conducted according to Malaysian International Organization for Standardization (MS ISO) and Technical Association of the Pulp and Paper Industry (TAPPI). The unbeaten durian rind CMP pulp (control pulp) was beaten by using PFI mill at three (3) different beating levels; 1000, 2000 and 3000 revolutions. It was found that durian rind CMP pulp drainage time was increased (longer time) and freeness level was decreased as the beating revolutions were increased compared to the control pulp. The result shows that paper bulk density and overall mechanical characteristics (tensile index, tear index, burst index and folding no.) of 60 gsm durian rind CMP hand sheets were increased with the increment of beating revolutions.

Keywords: Durian, *Durio Zibethinus Murr.*, durian rind, beating, chemi-mechanical, pulp

Abstrak

Kesan proses pemukulan ke atas ciri-ciri pulpa dan kertas yang dihasilkan daripada kulit durian melalui proses pempulpaan kimia-mekanikal (CMP) telah dikaji. Semua proses dan ujikaji yang terlibat di dalam kajian ini telah dijalankan merujuk kepada Organisasi Piawaian Antarabangsa Malaysia (MS ISO) dan piawaian Persatuan Teknikal Industri Pulpa dan Kertas (TAPPI). Pulpa CMP kulit durian tanpa kesan pemukulan (pulpa kawalan) telah dipukul menggunakan pengisar PFI pada tiga (3) tahap pemukulan yang berbeza iaitu 1000, 2000 dan 3000 putaran. Didapati masa penyaliran pulpa telah meningkat (masa yang lebih lama) dan tahap kebebasan telah menurun dengan peningkatan putaran pemukulan berbanding pulpa kawalan. Keputusan kajian juga menunjukkan bahawa ketumpatan pukal dan keseluruhan ciri-ciri mekanikal (indeks tegangan, indeks koyak, indeks pecahan dan bilangan lipatan) kertas 60 gsm yang dihasilkan daripada pulpa kimia-mekanikal kulit durian telah meningkat dengan peningkatan putaran pemukulan.

Kata kunci: Durian, *Durio zibethinus Murr.*, kulit durian, pemukulan, kimia-mekanikal, pulpa

1.0 INTRODUCTION

Nowadays, a lot of research works were conducted on turning the durian rind/husk/shell/peel wastes into value-added applications such as particle boards [1, 2], composites [3–5], lightweight construction materials [6–8], desiccant for air conditioning system [9], sorbent materials [10, 11], activated carbons [12–14] and carboxymethyl cellulose(CMC) [15]. These achievements show that durian rind offers a great potential as an alternative non-wood based raw material and alternative source of natural fibers.

Durian (*Durio zibethinus*) is the most popular seasonal fruit in South East Asia countries, particularly Malaysia, Indonesia, Thailand, and Philippines [16–18]. According to Ministry of Agriculture and Agro-based Industry Malaysia (MOA) report [19], the production of durian fruits from 2006 until 2014 has achieved between 277,767 metric tons to 376,565 metric tons per year. As reported, 40% of durian skin fiber can be generated from 1 kg of durian fruit [20]. Durian only has 20-35% parts that can be eaten, and the peels (60-75%) is dumped as trashes [21]. Thus, huge amounts of the durian shells (as waste products) are disposed of, burnt or sent to landfills, causing a severe problem in the community and environment [22, 23].

Durian rind provides one such good source for cellulose [15]. A recent studies show durian rind have rich hemicelluloses content [1, 5, 7, 24] that suitable for papermaking material. Durian skin fiber(DSF) is renewable, biodegradable and cheap thus suitable for packaging applications [25]. Nevertheless, to the best of author's knowledge, there is a lack of research works and published articles on the utilization of durian rind as an alternatives pulp and paper material. In order to overcome this condition, chemi-mechanical pulping (CMP) of durian rind study has been explored in our previous study [26, 27]. The findings of the study indicated that durian rind has bright potentials to be applied as a newly explored raw material for pulp and paper industry. However, the virgin pulp established by Masrol, Ibrahim and Adnan [26] needs a mechanical treatment especially refining process to improve the current physical and mechanical characteristics.

Beating process is usually applied to improve the unbeaten virgin paper which characterized by low strength, bulkiness, surface roughness and not suitable for papermaking [28]. Recent studies reported that beating process is suitable for enhancing the paper characteristics. The main aim of refining is to improve the fiber–fiber bonding [29, 30]. Refining increased the surface charge, specific surface area and specific volume of fibers, but did not change the total fiber charge relevant to the improvement of fiber-to–fiber bonding [31]. In papermaking, beating process is used to improve bonding and develop optimum strength properties, deliberately enlarges the fiber surfaces [32]. The three major effects of beating/refining listed by Bhardwaj, Duong and Nguyen [28] are: internal fibrillation caused by the breakdown of fiber walls into separate lamellas which increases the flexibility of fibers so that during sheet formation the fibers conform to and around one another producing large areas of intimate contact; external fibrillation described as the creation and/or exposure of fibrils on the surface of the fibers; and generation of fines from fibers when these are no longer able to sustain compressively and/or shear forces during the treatment.

The beating of the pulp influences various pulp properties such as freeness, specific surface area, specific volume, surface charge, total charge and elastic modulus, that they really improve the stretch properties of paper sheets [33]. Mohd Hassan, Muhammed, and Ibrahim [34] shows beating process enhances the Semantan Bamboo paper strength, as the beating process makes the fiber more flexible and enhanced the fiber to fiber bonding. The external and internal fibrillation causes the fiber to become more flexible and conformable, and thus, also increase the surface contact area between fibers during paper formation [34]. The improvement of the fiber flexibility due to beating process causing fibers to easily collapse during the paper making process and contributes to higher fiber-to-fiber bonding [34]. A recent studies by Masrol *et al.* [35,36] also shows soda-AQ oil palm male flower spikes characteristics were enhanced by the beating process.

Freeness is the measurement of the amount of water in a pulp suspension which could pass through a mesh screen, used to monitor the occurred changes during the stock preparation [37]. Refining also effects the drainability of the pulp. A review by Gharekhani *et al*. [37] concludes that refining reduces pulp drainability and also freeness due to fiber swelling and fines. Similar condition of freeness and pulp drainability reduction by refining process also reported by several studies [30,31, [35,38].

The objective of this study is to investigate the effect of beating on the characteristics of paper derived from durian rind under chemi-mechanical pulping process. The results of beaten pulp were compared with our previous study by Masrol *et al*. [26] in order to enhance the characteristics of unbeaten durian rind CMP pulp and paper. Therefore, the findings of this study would contribute to the pulp and paper industry and durian fruit waste disposal solutions.

2.0 METHODOLOGY

2.1 Raw Material Preparations

The durian rinds were collected from a local farm at Batu Pahat, Johor, Malaysia after the arils or fleshes were taken away. The raw material preparation was established by our previous study [26]. First, the collected durian rinds were cleaned and washed from any dirt and residues. The center vertical wall that separates the arils was removed using a sharp knife. Next, the spikes were removed with a cutter after the durian rinds were sliced approximately at 5-10 mm of thickness. Then, the durian rind slices were cut into small cubes with approximately similar thickness. After that, the durian rind cubes were naturally dried under direct sunlight for about 3-5 days to reduce the moisture content. As reported, the drying process of durian husk can be economically carried out under the sun [24]. Finally, the dried durian rinds were stored in a closed air-tight container at room temperature to prevent fungus infestation and moisture absorption.

2.2 Chemi-mechanical Pulping Process

In this research, the control unbeaten pulp was produced by chemi-mechanical pulping (CMP) process according to the control conditions as shown in Table 1 established by Masrol *et al*. [26]. First, the naturally dried durian rinds were treated with 10% Sodium Hydroxide (NaOH) based on oven-dry (o.d.) weight for 2 hours with liquor to the material ratio of 6:1 at room temperature. After the completion of NaOH treatment, the treated durian rinds were washed with running water. Next, the treated durian rinds were refined by Sprout-Waldron model D2A505 refiner mechanical pulping (RMP) machine to produce the CMP pulp. Then, the CMP durian rind pulp was subjected to a screening process using PTI Sommerville Fractionators according to TAPPI T 275 standard with a slot size of 0.15 mm to screen out the oversized debris. After that, the screened pulp was spin-dried using a Neng Shin extractor to remove excess water and dispersed into smaller size using the Hobart Mixer. Finally, durian rind CMP pulp was kept inside chillers at a temperature of 6°C.

Table 1 Chemi-mechanical pulping conditions of durian rind[26]

Pulping conditions	Value
Active alkali - NaOH (%) based on oven-dried (o.d) weight	10%
Time for active alkali treatment (hr)	2 hours
Liquor to raw material ratio	6:1

2.3 Beating process

In beating process, a laboratory PFI mill machine located at Pulp and Paper Laboratory in the Forest Research Institute Malaysia (FRIM) used to beat the screened pulp according to TAPPI T-248 "Laboratory Beating of Pulp (PFI mill method)" up to three different beating revolutions which are 1000 revolutions, 2000 revolutions and 3000 revolutions similar to Masrol *et al.* [35]. The low beating revolutions were chosen due to the low level of freeness and drainage time by the unbeaten durian rind CMP pulp. Unbeaten CMP pulp from our previous study [26] was compared as a control pulp. In order to produce laboratory hand sheets of 60 gsm paper grammage, 24 g oven-dry (o.d.) weight of durian rind CMP pulp is required. Pulp moisture content percentage was measured to determine the air-dry (a.d.) pulp weight needed for papermaking. The air-dry (a.d.) weight of durian rind CMP pulp was added into the disintegrator with the addition of 2 liters of water and operates for 2000 rotations to form pulp fiber slurry. After that, the disintegrated pulp was screened to remove water. Once again, the pulp containing residual water was then weighted to reach a weight of 240 g (10% consistency).

For beating process, durian rind CMP pulp was added into the PFI mill by sticking it uniformly on the wall of the bedplate. First, the stainless steel roll with chiseled bars of PFI mill was pointed down. Next, the machine was left to run until the count of 75 without beating the pulp to stabilize the pulp on the wall. Then, the blade valve was pushed up and the pulp was beaten for the required beating revolutions. After reaching the required beating revolutions, the machine was switched off and the beaten pulp was removed. Finally, the beaten pulp was once again disintegrated inside the disintegrator for another 600 rotations before laboratory hand sheets preparation process.

2.4 Laboratory Hand Sheets Preparation

The laboratory hand sheets were produced using a semi-automatic sheet machine (British Hand-sheet Machine) according to TAPPI T 205 sp-02 Forming Hand-sheets for Physical Tests of Pulp and MS ISO 5269-1:2005, IDT Pulps – Preparation of Laboratory Sheets for Physical Testing - Part 1: Conventional Sheet-Former Method. The durian rind CMP laboratory hand sheets were produced according to a grammage of 60±3 gsm. The pulp drainage time was evaluated according to TAPPI T221-cm 99: Drainage time of pulp. The CSF freeness test was performed according to the TAPPI T 227 om-99: Freeness of Pulp (Canadian Standard Method) by an L&W freeness test apparatus. The laboratory hand sheets were dried and conditioned at 23 ± 1°C and 50 ± 2% RH according to TAPPI T 402 sp-03 Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets and Related Products and MS ISO 187: 2001: Paper, board and pulps - Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples (ISO 187:1990, IDT) for at least 24 h before further evaluation and analysis.

2.4 Characteristics' Test

The structural, mechanical and optical characteristics test were performed inside a control room with controlled temperature (23.0±1˚C) and humidity environment (RH=50. 0±2%) as stipulated in TAPPI T 402 sp-03 Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets and Related Products and MS ISO 187: 1990, IDT MS ISO 187: 2001: Paper, board and pulps - Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples (ISO 187:1990, IDT). The sampling was conducted according to MS ISO 186: 2003: Paper and board - Sampling to determine average quality (ISO 186:2002, IDT).

Characteristics tests were conducted according to Malaysia ISO (MS ISO) standard as listed in Table 2.

Table 2 Characteristics' test and standard

No.	Test	Standard
a.	Grammage	MS ISO 536: 2001: Paper and Board – Determination of Grammage
b.	Moisture Content	MS ISO 287: 2010: Paper and Board – Determination of Moisture Content of a Lot – Oven Drying Method (ISO 287: 2009, IDT)
c.	Thickness	MS ISO 534: 2007: Paper and Board – Determination of Thickness, Density and Specific Volume
d.	Brightness	MS ISO 534: 2007: Paper and Board – Determination of Thickness, Density and Specific Volume (ISO 534: 2005, IDT)
e.	Opacity	MS ISO 2470-1: 2010: Paper, Board and Pulps – Measurement of Diffuse Blue Reflectance Factor-Part 1: Indoor Daylight Conditions -ISO Brightness- First revision (ISO 2470-1: 2009, IDT)
f.	Tensile	MS ISO 2471: 2010: Paper, Board and Pulps – Determination of Opacity (Paper Backing) – Diffuse Reflectance Method - First revision (ISO 2471: 2008, IDT)
g.	Tear	MS ISO 1924-2: 2010: Paper and Board – Determination of Tensile Properties – Part 2 – Constant Rate of Elongation Method - 20 mm/min – First revision (ISO 1924-2: 2008, IDT)
h.	Burst	MS ISO 1974: 1999: Paper – Determination of Tearing Resistance – Elmendorf Method – Second Revision (ISO 1974:1990, IDT)
i.	Folding	MS ISO 2758: 2007: Paper-Determination of Bursting Strength (ISO 2758: 2001, IDT)

3.0 RESULTS AND DISCUSSION

3.1 Pulp Characteristics

Table 3 shows the CSF freeness level and drainage time for each condition of durian rind CMP pulp. Durian pulp CSF freeness level is low due to the nature of the durian rind that absorbs and holds water. As a result, the drainage time for papermaking was quite long to dewater. Durian rind CMP pulp CSF freeness level decreases from 89 mL to 30.5 mL with longer beating revolutions. Freeness decreased as the beating degree increased due to the increase in pulp wetness, fiber shortening and fines production [39]. Fines also retain more water than fibers and behave like a gel which causes pulp freeness to decrease[39].

Fines also reduce the drainage of water by filling pores in the sheet during paper sheet formation but still provide more fiber-to-fiber contact area. In that condition, drainage time for durian rind unbeaten CMP pulp increases (longer time) as longer beating revolutions were applied (Table 3). Drainage time increased as refining degree was increased due to an increase in fiber shortening and fine production [39]. Fines move freely and finally get stuck in the pores between fibers, which means blocking the water flow path and slowing the drainage [37].

Figure 1 illustrates that the durian rind CMP pulp level of CSF freeness has decreased and the drainage time was increased with increasing beating revolution. Durian rind CMP pulp obtained similar downtrend pattern of freeness and uptrend of drainage time (longer) by the effect of beating process compared to other previous studies by Masrol *et al*. [35] and Rushdan *et al*. [40] as presented in Table 6. This condition contributes to the improvement of paper sheet density and strength since the wet fibers could pack firmly between them during the water removal.

Table 3 Effect of beating revolution to the durian rind CMP pulp characteristics

Sample	Drainage Time (s)			CSF Freeness (mL)
	Drainage Time (s)	STDV	CoV (%)	
0 rev[26]	74.38a	3.96	5.33%	89.00a
1000 rev.	100.25b	7.14	7.12%	75.25b
2000 rev.	109.60c	6.27	5.72%	66.25c
3000 rev.	226.00d	6.84	3.03%	30.50d

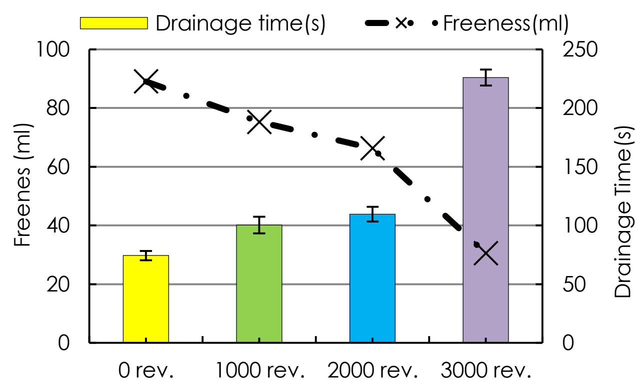


Figure 1 The effect of beating revolutions to the durian rind CMP pulp freeness and drainage time

3.2 Physical Characteristics

Table 4 shows the effects of beating revolutions on the durian rind CMP paper physical characteristics. The grammage result shows that laboratory hand sheets formation achieved the standard grammage target of 60±3 gsm. Meanwhile, bulk thickness shows a downtrend pattern with the effect of beating revolutions as the 3000 rev. beaten pulp showing the lowest value (116.35 μm) compared to 128.59 μm by the control unbeaten pulp.

However, the bulk density of durian rind CMP paper shows an increasing trend as the beating revolution was increased due to the increment of fiber flexibility and relative bonding. Fiber flexibility and the relative bonding area can be determined indirectly by the paper apparent density [40]. Apparent bulk density increased as the beating revolutions increased and influences almost all mechanical, physical, and electrical properties [40]. The uptrend pattern of durian rind CMP bulk density as the beating revolutions increased was similar with the findings of previous studies as shown in Table 6.

Table 4 The effects of beating revolutions to the durian rind CMP hand sheet physical characteristics

Pulp Condition	Grammages (g/m²)	Bulk Thickness (µm)		Paper bulk density (g/cm³)	
		Mean	STDV	Mean	STDV
Unbeaten[26]	58.87	128.59	1.99	0.46	0.007
1000 rev.	60.08	121.43	1.02	0.49	0.004
2000 rev.	61.02	119.40	1.08	0.51	0.005
3000 rev.	61.69	116.35	1.20	0.53	0.005

3.3 Mechanical Characteristics

Table 5 shows that overall mechanical characteristics were enhanced by the beating revolution in a range between 0 until 3000 revolutions. Tensile index, tear index, burst index and number of folds were increased with the increment of beating revolution from 0 until 3000 revolutions which are similar with the findings of a previous study by Masrol *et al*. [35]. As the beating revolution increased, the fiber to fiber bonding became closer to each other and high strength of stress was needed to break the paper sheet, thus increased the tensile index with the increasing of the beating revolutions [41]. Increasing beating revolutions resulted in high fiber flexibility and fiber swelling due to fibrillation and the presence of more fine fiber content, then promoted better inter- fiber bonding within the paper formation and thus led to an increase in burst and tensile strength values [30]. Tear index was increased as the revolution number increased; fiber coarseness was reduced while their strength and the combination and friction among fibers enhanced. The folding endurance rose linearly with the increasing of beating revolutions [41]. Overall tensile index, tear index, burst index and number of the fold readings for durian rind CMP pulp that have beaten with 0 revolutions until 3000 revolutions were increased as the bulk density was increased; as illustrated in Figure 2 – Figure 5. The paper became denser and more pressure is required to break the inter-fiber bonding thus producing higher bursting index [34].

The comparative effects on the characteristics of durian rind CMP paper and other types of paper are given in Table 6. It can be seen, durian rind CMP hand sheets mechanical characteristics were comparable and show similar findings of beating effects compared to other previous researchers working with various wood and non-wood based materials (Table 6).

Table 5 The effects of beating revolutions to the durian rind (DR) CMP hand sheet mechanical characteristics

DR CMP pulp properties	Control-unbeaten[26]	1000 rev.	2000 rev.	3000 rev.
Tensile Index (Nm⁄g)	34.67	36.22	37.43	40.00
Tear index (mN.m²/g)	4.78	5.10	5.56	6.19
Burst Index (kPa.m²/g)	1.86	1.94	2.11	2.40
Double Fold (No.)	15	17	21	33

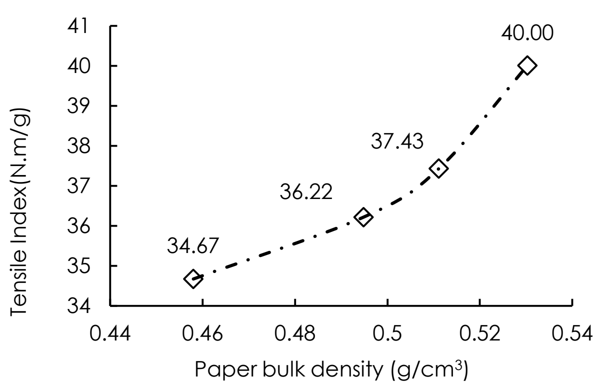


Figure 2 The effect of paper bulk density on tensile index of durian rind CMP hand sheet

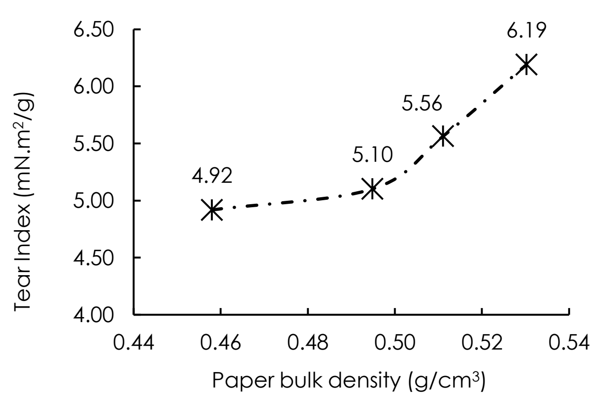


Figure 3 The effect of paper bulk density on tear index of durian rind CMP hand sheet

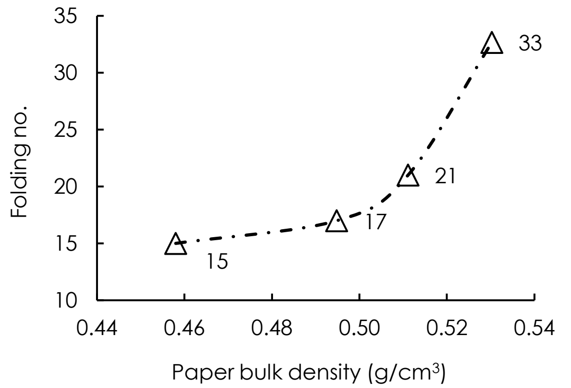


Figure 4 The effect of paper bulk density on folding no. of durian rind CMP hand sheet

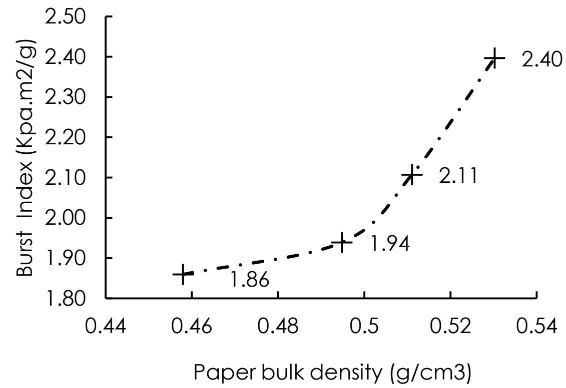


Figure 5 The effect of paper bulk density on burst index of durian rind CMP hand sheet

Table 6 Comparisons of beating effects on the durian rind CMP paper characteristics

Paper/characteristics	Beating revolutions									
	0	**1000**	**2000**	**3000**	**4000**	**5000**	**6000**	**8000**	**16000**	**24000**
Durian rind CMP- current study										
Drainage(s)	74	100	110	226	-	-	-	-	-	-
Freeness	89.00	75.25	66.25	30.50	-	-	-	-	-	-
Apparent bulk density(g/cm³)	0.46	0.49	0.51	0.53	-	-	-	-	-	-
Tensile index (Nm/g)	34.67	36.22	37.43	40.00	-	-	-	-	-	-
Tear index (mN.m²/g)	4.78	5.10	5.56	6.19	-	-	-	-	-	-
Burst index (kPa.m²/g)	1.86	1.94	2.11	2.40	-	-	-	-	-	-
Fold (no.)	15	17	21	33	-	-	-	-	-	-
Oil palm male flower spikes (OPMFS) – Soda-AQ[35]										
Drainage(s)	6.42	13.23	16.32	23.70	-	-	-	-	-	-
Freeness(CSF)	353	195	120	103	-	-	-	-	-	-
Apparent bulk density(g/cm³)	0.43	0.61	0.66	0.69	-	-	-	-	-	-
Tensile index (Nm/g)	39.10	46.25	52.52	54.66	-	-	-	-	-	-
Tear index (mN.m²/g)	8.32	8.56	9.19	9.25	-	-	-	-	-	-
Burst index (kPa.m²/g)	3.15	4.23	4.32	4.37	-	-	-	-	-	-
Fold (no.)	38.5	190	252.5	347	-	-	-	-	-	-
***Gigantochloa scortechinii* (Semantan Bamboo)-Soda-AQ**[41]										
Tear index(mN.m²/g)	32.54	41.23	49.36	55.75	62.22	64.37	69.05	75.54	82.66	16.64
Tensile index (Nm/g)	13.45	23.03	27.13	25.66	24.01	22.38	21.58	17.97	17.33	83.90
Burst index (kPa.m²/g)	1.54	2.58	3.51	4.27	4.79	5.22	5.41	5.88	6.84	6.67
Fold(no.)	6	48	283	618	1161	1201	1273	1294	1494	1769
Empty fruit bunches (EFB) of *Elaeis guineensis*- Soda-AQ[40]										
Freeness (CSF)	623	528	479	414	-	-	-	320	-	-
Apparent Density (g/cm³)	0.47	0.52	0.54	0.57	-	-	-	0.60	-	-
Tear index (mN.m²/g)	5.85	6.73	8.35	7.71	-	-	-	7.84	-	-
Tensile index (Nm/g)	21.37	27.58	30.98	34.39	-	-	-	36.86	-	-
Burst index (kPa.m²/g)	1.41	1.90	2.11	2.45	-	-	-	2.80	-	-

Acacia mangium*[40]					***Eucalyptus Globules***[40]				
Beating revolutions	**0**	**750**	**1500**	**2250**	**Beating revolutions**	**0**	**750**	**1500**	**2250**
Freeness (CSF)	650	375	100	45	Freeness (CSF)	550	500	400	275
Apparent Density (g/cm³)	0.49	0.65	0.62	0.59	Apparent Density (g/cm³)	0.54	0.70	0.78	0.83
Tear index (mN.m²/g)	3.28	7.39	6.34	5.71	Tear index (mN.m²/g)	4.33	13.47	12.39	11.34
Tensile index (Nm/g)	2.53	10.23	10.34	10.29	Tensile index (Nm/g)	24.84	91.40	91.40	92.62
Burst index (kPa.m²/g)	6.76	7.20	7.25	7.44	Burst index (kPa.m²/g)	0.13	6.02	6.71	6.65

3.4 Optical Characteristics

Table 7 shows that there is no significant effect of beating revolutions on the optical properties since there is no delignification process involved in beating process. Table 8 indicated that durian rind CMP ISO brightness (13.20 %) is lower compared to other types of pulp. Nevertheless, bleaching process or another pulping method such as soda-anthraquinone should be taken into consideration in the future in order to enhance the low brightness of durian rind CMP pulp and paper. Muhammad Jani and Rushdan [42] indicated that multistage bleaching process of the pulp provides a much greater improvement in brightness. Hand sheets made from soda-AQ pulp gave higher in brightness due to the reduction of Kappa number by the addition of anthraquinone (lignin content) [43, 44].

Table 7 The effect of beating revolutions to the durian rind CMP paper optical characteristics

Pulp Condition	ISO Brightness (%)			ISO Opacity (%)		
	Mean	STDV	CoV (%)	Mean	STDV	CoV(%)
Unbeaten [26]	13.20	0.80	6.03	97.73	1.09	1.12
1000 rev.	13.44	1.18	8.78	97.48	0.49	0.51
2000 rev.	13.73	0.83	6.00	98.17	0.32	0.32
3000 rev.	13.56	1.28	9.45	98.21	1.08	1.10

Table 8 Comparison of durian rind CMP paper optical characteristics

Paper	Pulping method	Brightness (%)	Opacity (%)
Durian rind CMP	Cold CMP	13.20	97.73
Coir[42]	Cold CMP	16.28	99.60
Coir[45]	Soda-AQ	22.93	99.35
Empty fruit bunch [46]	Soda-AQ	37.27	95.26
Old corrugated carton (OCC) [46]	-	26.17	99.38
Old newspaper (ONP) [46]	-	54.02	98.69
Old copier paper (OCP) [46]	-	64.48	98.91

3.5 Scanning Electron Microscopy (SEM) Analysis

Figure 6a shows the top surface of unbeaten durian rind paper in 500x magnification. Figure 6b shows the top surface SEM image of durian rind paper made from beaten pulp at 3000 PFI revolutions in 500 x magnification. Figure 6(b-c) clearly illustrates that the fiber arrangement of durian rind pulp beaten with 3000 PFI revolutions is straighter, fewer crimps and kinks compared to an unbeaten pulp. If fibers are straight and deformation-free, all segments in the network are ready to transmit the load from one bond to another when the network is strained resulting in the stress being uniformly distributed in the network [47]. The area of interaction between fiber-to-fiber also increased as the beating revolution increased. Properties of durian rind paper were enhanced through the fiber to fiber uniform internal defibrillation by the effect of beating. The durian fiber vessels and pit holes are much clearer as the beating time is increased up to 3000 PFI revolutions compared to an unbeaten pulp as shown in Figure 7 (a-b).

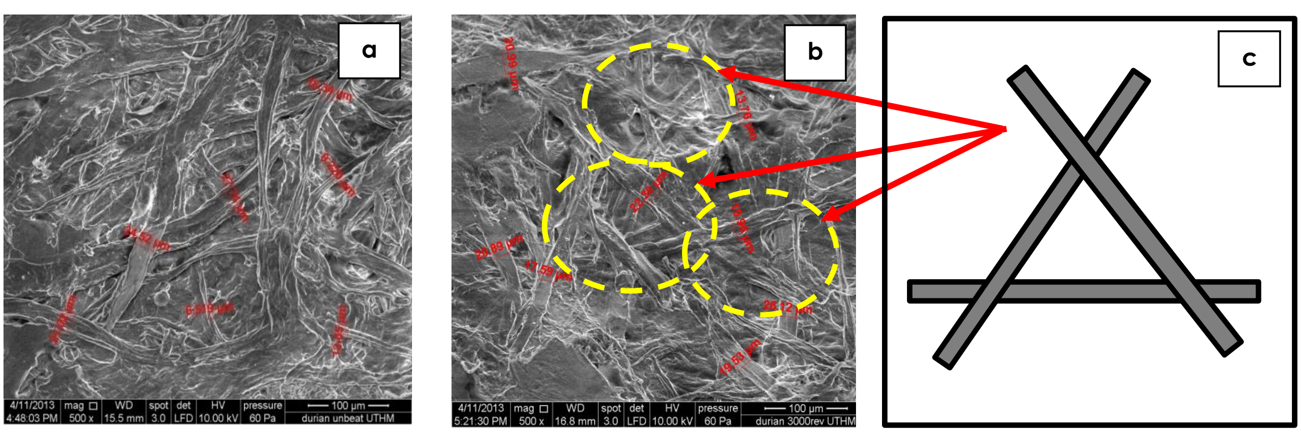


Figure 6 Top SEM image in 500x magnification of CMP: (a) unbeaten durian rind paper[26]; and(b) PFI revolution = 3000 durian rind paper (c) straight triangle overlap segment

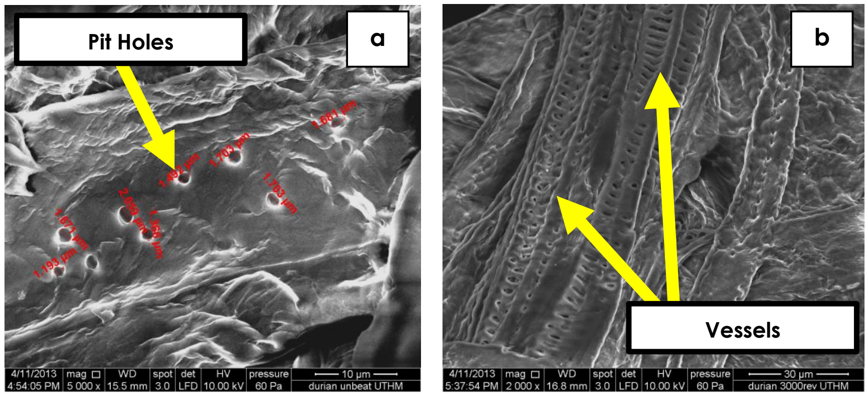


Figure 7 Top SEM image of: (a) Unbeaten durian rind paper in 5000x magnification[26];and (b) PFI revolution = 3000 durian rind paper in 2000 x magnification

4.0 CONCLUSION

The results of the research showed that increasing in beating revolution has improved overall physical and mechanical characteristics of durian rind chemi-mechanical pulp and paper. The durian rind CMP pulp freeness level was decreased and drainage time was increased as beating revolution increased. Mechanical characteristics of durian rind 60 gsm CMP paper were increased by 15.38 % for the tensile index; 25.91 % for tear index; 28.87 % for burst index and 117.18 % for the number of folds due to the increment of beating revolution. There is no significant effect of beating process to the optical characteristics (brightness and opacity). As recommendations, bleaching process and another type of pulping method such as soda-anthraquinone (soda-AQ) should be taken into consideration in order to improve the pulp brightness. This research finding proves that durian rind could be a promising alternative non-wood based raw material for pulp and paper industry, thus also beneficial to the durian industry. As a conclusion, this preliminary work determined that durian rind offers a great potential to be applied as a newly explored material for pulp and paper industry.

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