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The Effect of Pulp Beating on Physical and Mechanical Properties of Paper Developed from Kenaf

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Abstract

Kenaf (Hibiscus cannabinus L.) is addressed as a potential renewable non-food fibre crop used in various industrial applications including pulp and paper industry. Within Malaysia context, the government is strongly promoting the R&D on kenaf as the substitute and cost effective fibre resources for manufacturing particleboard, fibreboard and textiles. For fabrication of speciality papers, it was reported in the literature that the papers' properties were highly correlated to methods of pulp treatment. The main objective of the work series is to investigate the properties of oil filter paper developed from kenaf bast fibre for application in automotive industry. In this article, we report the impacts of pulp treatment to physical and mechanical properties of the oil filter paper products. The kenaf fibre pulp was prepared through soda pulping method using the Soda- Anthraquinone chemical. Then, the pulp were subjected to various beating degree ranging from 1000 - 4000 revolutions and pressed to form paper sheets. All the physical and mechanical properties of the paper sheets were tested according to TAPPI and ISO standards. The results demonstrated that the overall physical and mechanical properties of paper products were influenced and enhanced by the beating process. Kenaf paper sheet at 4000 beating revolution exhibits the best tensile index of 46.79 N.m/g, burst index value of 3.25 kPa.m2/g and 121 Number (No.) of double fold endurance. The strength property of kenaf paper produced at 4000 rev was comparable to the commercial Original Equipment Materials. These data were supported by microstructural observation using the Scanning Electron Microscope (SEM). Micrograph of paper sheet produced under optimized conditions indicates the presence of fines that seemed to increase fibre conformability and improved the inter-fibre bonding within the paper formation. The results implicate the potential development of kenaf fibre to be further explored as a renewable resource for papermaking industry.

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1. Introduction

In conjunction to the worldwide demand for fibrous material, increasing deforestation and environmental awareness, non-wood plants is becoming one of the most important alternative resources of fibrous material in 21st century (Ashori, 2006). These natural fibres are environmental friendly, cheaper, abundant and also known for having traits such as excellent strength and modulus (Thiruchitrambalam, Alavudeen, & Venkateshwaran, 2012). There is various non wood plant fibres that can be used for papermaking such as bagasse, bamboo, wheat and rice straws. These non-wood fibres are some of the example natural fibres used in production of pulp and paper globally. Conversely, kenaf (*Hibiscus Cannabinus L.*) is being researched and explored as a potential raw material for paper making in developing and developed countries (Ashori, Harun, Raverty, & Yusoff, 2006).

Kenaf is an herbaceous annual plant of the *Malvaceae* family. It is a fast growing plant which can reach to more than 3 meter of heights within 4 months period. The kenaf stem is made of bast (34-38 %) and the rest are core fibres. Its bark are fibrous and traditionally used to make ropes and textiles. In advanced research and developments, either its whole stem or the bark fractions are utilised to produce composites, absorbent materials and various type of papers. In Malaysia, the National Economic Action Council (NEAC) which is now known as National Economic Advisory Council under the directive of YAB Prime Minister inaugurated the Kenaf Project since 1999. In order to study the potential of growing kenaf in Malaysia as an industrial crop, NEAC formed a steering team to promoting R&D on kenaf. Moving on, the research on kenaf in Malaysia was initiated with evaluation of kenaf adaptability, identification of suitable cultivars for industrial and agriculture application, agronomical management and inputs, end products and cost production.

A key research focus on end products is the application of kenaf fibre in paper making industry. The success of kenaf in papermaking have been dependent on its bast fibres with low lignin content. The chemical composition of kenaf fibres not only complies to the standard set by pulp and paper industry in Malaysia, kenaf pulp could be fabricated into paper with higher strength than of conifer-based paper(Hadi, Basri, Abdu, Junejo, & Hamid, 2014). For kenaf paper production, kraft and soda pulping are two of the most frequently used pulping process (Villar, Revilla, Gómez, Carbajo, & Simón, 2008). Although the overall scenario seems promising, one of the key technical challenge faced by the paper industries to produced speciality paper is on the modification of the pulp or the fibre quality in order to enhance the paper's features. Therefore, R&D work to improving fibre quality for all types of pulp sources is in great demand by the industry.

One of the processes in the stock preparation is defined as pulp refining or beating. Pulp refining or beating (Gharehkhani et al., 2015)can also be explained as a mechanical treatment of the pulp by using an instrument called as refiner and both terms carry the similar meaning, therefore the term "beating" is adopted in this study to keep the consistency throughout the text. Beating of chemically treated pulp is an essential step to increase the bonding ability of fibres making a diverse of simultaneous differences in fibres for example internal fibrillation, external fibrillation, fibre shortening and fines formation (Ulfa, Trisunaryanti, & Setiaji, 2014). In addition, beating of pulp is also taken into account to elevate the characteristics of paper sheets (Jianyong & Jianchun, 2015). Several recent development of specialized paper from kenaf reported positive outcomes. A study to investigate the effects of beating on the physical and mechanical properties of untreated kenaf based insulation pulp has concluded that beating of the pulp does affect the thickness, density and tensile index of the paper (Umair, Azis, Halis, & Jasni, 2018). A research had also been carried on comparing and contrasting kenaf properties as a potential for linerboard production and beating of the pulp has been applied to observe the effects on the pulp properties as well (Mossello, Harun, Ibrahim, et al., 2010). In the literature, the selection of pulping conditions were carefully selected based on the aimed properties of targeted end products.

The main aim of our work is to investigate pulp beating parameters for the purpose of developing oil filter paper from kenaf for application in automotive industry. In this first publication of our work series, we report the effects of different beating revolution on physical and mechanical characteristics of papers produced from kenaf bast fibre. Moreover, surface morphology analysis have also been carried to observe the changes that happen to the paper sheets fibre arrangement at different beating revolutions. The properties of kenaf paper products were also compared to the commercial Original Equipment Manufacturers (OEM) oil filter element. The current study is significantly important to provide fundamental data for future R & D to enhance kenaf pulp properties and subsequently the quality of speciality paper made from kenaf fibres.

2. Methodology

2.1 Raw Material Preparation

Mature kenaf bast fibres were obtained from the National Kenaf and Tobacco Board of Malaysia. An amount of 1.0 kg kenaf bast fibres was cut into ~1cm in length to obtain shorter fibres for pulping process and oven dried to ~13% moisture. In addition, two different types of commercial oil filters were purchased from local OEM supplier. The commercial filter elements made from woody cellulose pulps were extracted and analysed for various properties.

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2.2 Pulping Process

The pulping process were carried out in the Pulp and Paper Laboratory of Forest Research Institute Malaysia (FRIM). The dried bast fibres were pulped using the Soda-AQ method in a rotary digester. The pulping conditions used are shown in Table 1.

Table 1: Soda AQ pulping conditions and parameters

Soda AQ pulping condition	Parameter
AQ based on dry fibre (%)	0.1
NaOH based on dry fibre (%)	18
Fibre/Liquor ratio	1:6
Initial temperature (℃)	34
Time to 170 ℃ (minutes)	90
Time at 170 ℃ (minutes)	120

The kenaf bast fibre pulp from the rotary digester was then disintegrated into the hydropulper with water to remove the remaining black liquor. After that, screening of the pulp was carried out using the PTI Sommerville Fractionators according to TAPPI T-275 standard with a slot size of 0.15mm. Then, the pulp was then swirled into a spinning machine to minimize the moisture and water content. Later on, the kenaf bast fibre pulp was then dispersed by using the Hobart Mixer. Next, the pulp yield percentage was determined and the pulp was stored inside the chiller at 6℃ prior to beating process.

2.3 Preparation of Kenaf Paper and Characterisation Study

Several guidelines and standards described by the Technical Association of the Pulp and Paper Industry (TAPPI) were used at these stages. Firstly, the screened pulp was beaten at four different revolutions (1000, 2000, 3000, 4000 rev) using the PFI mill machine according to TAPPI T-248 "Laboratory Beating of Pulp (PFI mill method). Unbeaten pulp (0 revolution) acted as a control in this experiment. The paper sheets were prepared according to TAPPI T-205 "Forming Handsheets for Physical Tests of Pulp". The kenaf bast fibre paper sheets were then made using the semi-automatic hand sheet forming equipment. In addition, according to the TAPPI T-227, "Freeness of pulp (Canadian standard method)", the value of freeness of the pulp was studied. Then, the physical and mechanical properties tests of produced paper sheets were analysed using the TAPPI T-220 "Physical Testing of Pulp Handsheets" standard. The properties of the papers were determined in a controlled temperature and humidity environment as stipulated in TAPPI T 402 "Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets and Related Products". In conjunction with TAPPI T-410 and TAPPI T-411 for grammage and thickness tests were also conducted. Similarly, the mechanical properties (tear and tensile indices) of OEM samples were also evaluated. The surface morphology of the pulp fibres were observed using a Scanning Electron Microscopy (SEM) (Quanta 200).

3. Results and Discussion

3.1 Kenaf Bast Fibre Yield

The kenaf bast fibre pulp showed a value of 65.07% for moisture content percentage and great yield percentage of 53 % of unbleached kenaf bast fibre pulp. The result has good agreement to reported yield data in the literature. (Monti, 2013) reported that pulp yield of whole kenaf stem ranged between 45-48 % for unbleached pulps and 41- 43 % for bleached pulps, which is 5 % lesser than the yields of wood pulps. Another study had showed standard yield range value of chemical pulping of 40- 55 % (Masrol et al., 2015.).

3.2 Physical and Mechanical Properties of the Kenaf Bast Pulp and Paper

Table 2 and Figure 1-2 show the characteristics of the kenaf bast pulps and paper prepared based on the Soda – AQ method. In general, the freeness and apparent density of the kenaf bast fibre pulp shows significant change as the beating revolutions increased.

Table 2: Kenaf bast pulp and Papersheet properties

Beating Revolutions	Freeness (ml)	Grammage (g/m^2)	Apparent Density (g/cm^3)
0	661.5	311.48	0.41
1000	603	211.94	0.47
2000	585	210.59	0.51
3000	545	208.51	0.55
4000	464	210.10	0.57

Note: Grammage control value is 200 gsm

Freeness of pulp measures how rapidly water can drain from a diluted pulp suspension prior to paper making process. High freeness value is normally undesirable to produce good quality paper. High freeness indicates faster water drainage from pulp dilutions that could lead to non-homogenised fibres web formation. In Table 2, the unbeaten pulp showed the highest freeness of 661.50ml (with standard error 2.19%) compared to the beaten pulps. There is tendency for pulp with low freeness to form aggregates during pressing especially if the pulp dilutions contains long fibres 4 to 5mm long (Jani & Rushdan, 2016). The flocculation of fibres will form paper with poor formation thus affecting paper's quality (Masrol et al., 2015).

The lowest freeness of 464.00 ml (with standard error 1.08 %) is observed for pulp beaten at 4000 revolutions. The result showed similar pattern in previous study in which summarised that the condition is such due to the rise in pulp wetness, fibre shortening and fines fabrication. Moreover, fines also retain more water than fibres and act alike as gel that cause pulp freeness to decrease (Masrol et al., 2015). It is believed that these fines massively contributed to the reduction of water drainage in paper making process by occupying the pores in the sheet, yet in align helps to increases the fibre-fibre contact area providing better surface area (Mossello, Harun, Md Tahir, et al., 2010). Fibres without fibrillation property and low flexibility most likely to result in poor wet web network in paper. These in turn leading to low strength, high porosity, weak bonding and poor formation (Jani & Rushdan, 2016). The results suggest that beating improves the percentage of fines in fibres, while reduces the freeness value as reported early (Samariha, 2011). Grammage (g/m^2) results (Table 2) shows that in general, all paper sheets condition achieved close to the control value which is 200gsm with less than 1% of percentage of standard error except for the unbeaten pulp which was 311.48g/m^2 and 1% percentage of standard error, which is slightly far from the planned grammage value. It can be also seen in Table 2 that as the beating revolutions increased, the apparent density increased and the highest value is recorded at 4000 beating revolutions, 0.57g/cm3. One of the most important property of paper is said to be apparent density as it acts as good indicator of fibre flexibility and fibre bonding (Mossello, Harun, Resalati, et al., 2010). Thus, beating had contributed in increasing the kenaf paper sheet's apparent density leading to better fibre bonding and increasing paper's strength as the beating times increases.

Figure 1 shows the relationship between beating revolution and tensile and tear indices and the change happened as the beating revolution increases. Tensile index and tear index are probably the most common properties for the direct measurement of the paper strength potential. It can be seen that the tensile index increased accordingly with the increasing beating revolution.

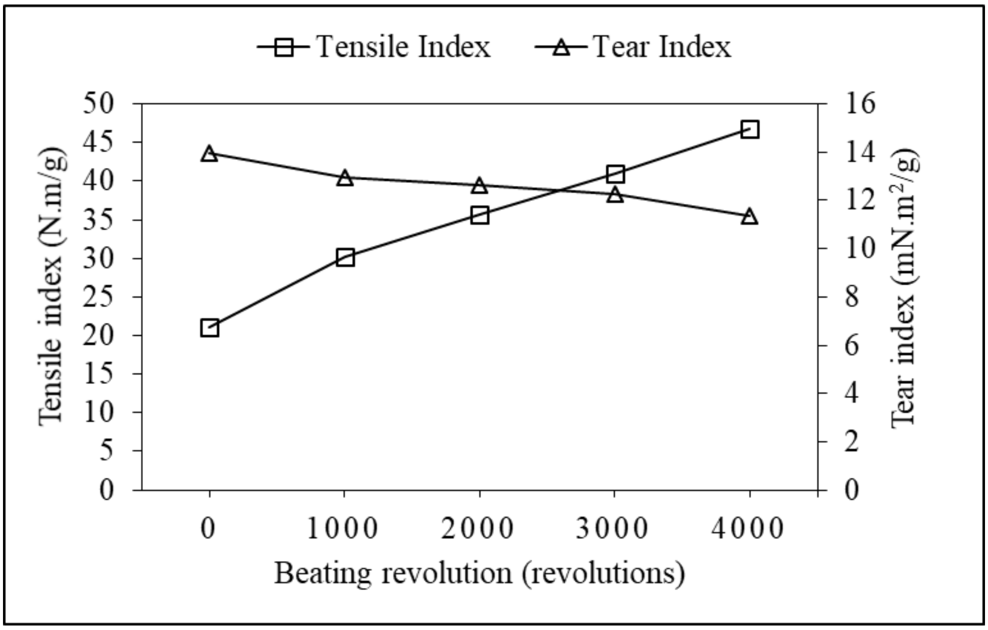

Figure 1: Tensile and tear indices of kenaf bast paper at different beating revolutions

At initial stage without any beating, the tensile index of the pulp at 0 revolutions is 21.07 N.m/g with percentage of standard error of 5.93% and the tensile gradually increased to 30.17 N.m/g, 35.67 N.m/g, 40.91 N.m/g and 46.79 N.m/g as the beating degree increased from 1000 revolutions to 4000 revolutions (with standard error 2.00- 4.00 %). The tensile strength increased during beating times due to improved fibre swelling, fibrillation, flexibility, hydrogen bond and fibre-to-fibre bonding (Ulfa et al., 2014).

A more complex form of stress transmission than tensile strength is significantly measured by tear strength. Tear is a estimation of the energy required to propagate an out-of plane tear failure line over a predetermined distance in a sheet of paper (Ulfa et al., 2014). It can be seen in Figure 1 that the tear index decreased whereas the tensile index increased as the beating revolutions increases. The unbeaten pulp (0 revolutions) has the highest tear index value of 13.98mN.m^2/g compared to the beaten pulps (1000-4000 revolutions),in which their tear indices fall within the range of 12-11 mN.m^2/g while the lowest tear index is seen for the pulp with 4000 beating revolutions which is 11.38mN.m^2/g. The percentage of standard error of the tensile indices for unbeaten and unbeaten also showed not more than 5%

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and all are within the range. The decline in tear strength is due to refining of the fibres during the beating revolutions resulting in increase of short fibres and reduces the bonding strength of fibres that causes the papers to tear easily. Similar results is also reported in previous study stating that tear index is very much related to strength and length of fibres, thus increasing the ratio of tiny fibres and reducing the fibre length results in declined tear index (Tingjie et al., 2016).

In addition, the following figure illustrates on the comparison of burst index and fold endurance of the kenaf bast. Paper sheets at different beating revolutions (Refer with: Figure 2). Apparently, burst index and folding endurance of the bast kenaf fibre paper sheets increased in parallel with the beating time.

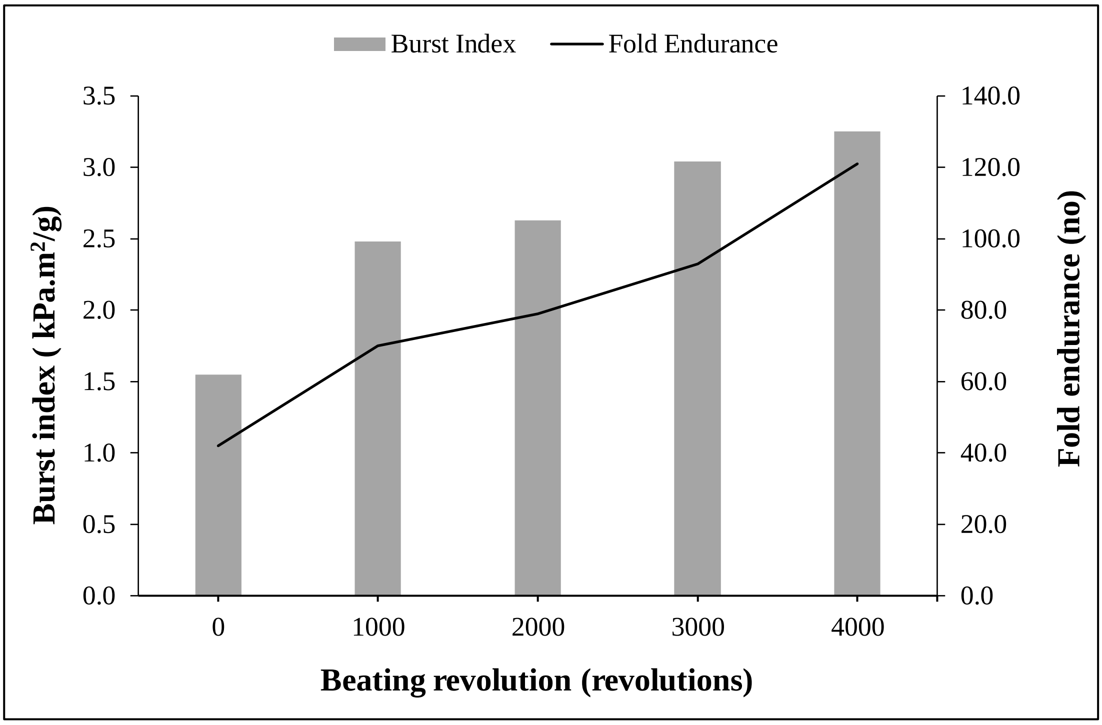

Figure 2: Burst index and fold endurances of kenaf bast paper at different beating revolutions

From Figure 2, it can be observed that both burst index and fold endurance show gradual increase as the beating revolutions were further improved from 0 revolutions to 4000 revolutions. The unbeaten pulp showed the lowest burst index and fold endurance values of 1.55kPa.m^2/g and 42 number of fold (no), (percentage of standard error range of 3% - 4%) compared to the all the beaten pulps. However, the highest and best result obtained for both burst index and fold endurance is at 4000 beating revolution which is 3.25kPa.m^2/g and 121 number of fold (no) with less than 1% of standard error. A similar results is also showed in previous study of using Chinese kenaf bast fibre (CBF), that the folding and burst strength of CBF pulps improved as the beating continued but at different tendencies (Nezamoleslami, Suzuki, & Kadoya, 1997).

In this study, the tensile and tear indices of kenaf bast fibre paper produced at 4000 rev beating was compared to two commercial OEM oil filter elements as benchmarking (Table 3).

Table 3: Strength properties of the Selected KBF Paper and OEM Oil Filter Papers

Particulars	KBF Paper (4000 rev)	OEM Sample 1	OEM Sample 2
Tensile Index (Nm/g)	46.79	25.73	39.8
Tear Index (mN.m^2/g)	11.38	16.31	13.86

From Table 3, it is observed that in general the tensile and tear indices of KBF paper produced at 4000 rev is comparable to both OEM samples. Among the samples, KBF paper shows the highest tensile index. Meanwhile, the tear index of KBF paper is very similar to both OEM samples. This suggests that KBF paper is stronger to withstand mechanical stress than OEM Sample 1 and OEM Sample 2. KBF paper also has well resistant to tearing force like the commercial oil filter elements. Since the comparison were made with commercial samples, the initial data implies that KBF paper produced at 4000 rev could further be developed to meet the standard requirements of oil filter element for automobile use.

3.3 Microstructure of the Kenaf Bast Paper

Paper from kenaf bast fibre intended for oil filtration have been produced with similar weight with slight variations but at different beating revolutions which were 0 revolutions (unbeaten), 1000 revolutions, 2000 revolutions, 3000 revolutions and 4000 revolutions. Obviously, the difference in the beating revolutions affects the distribution and microstructure web forming of fibres in the filter paper as observed in the Scanning Electron Microscope (SEM). Figure 3 showed SEM micrographs of the surface of the kenaf bast fibre paper for each beating conditions at 100 x, 200 x, 500 x and 1000 x magnifications in horizontal arrangement of separate rows where (a) is 0 revolutions or unbeaten, (b) is 1000 revolutions, (c) is 2000 revolutions, (d) is 3000 revolutions and (e) is 4000 revolutions.

It can be seen Figure 3 (a - e) in horizontal direction, from image 1 to image 3 that the diameter of the fibres became smaller as the beating revolutions increased and more fines are produced. Previous review has also stated that shortening of fibres due to beating process enhances sheet formation considerably, and responsible to paper uniformity and smoothness (Mossello, Harun, Md Tahir, et al., 2010). Moreover, it can be observed that beaten pulps had more pore formations compared to unbeaten pulp. The effects of beating process on the beaten pulps can be observed on the better formation of fibre webs as the beating revolutions increased compared to unbeaten pulp. The arrangement of the fibres were also improved along with increasing the beating revolutions creating higher bonding ability. Similar results were observed in previous study that suggested fibre arrangement for beaten pulps were more unwavering and greater connection of fibre (Masrol et al., 2015).

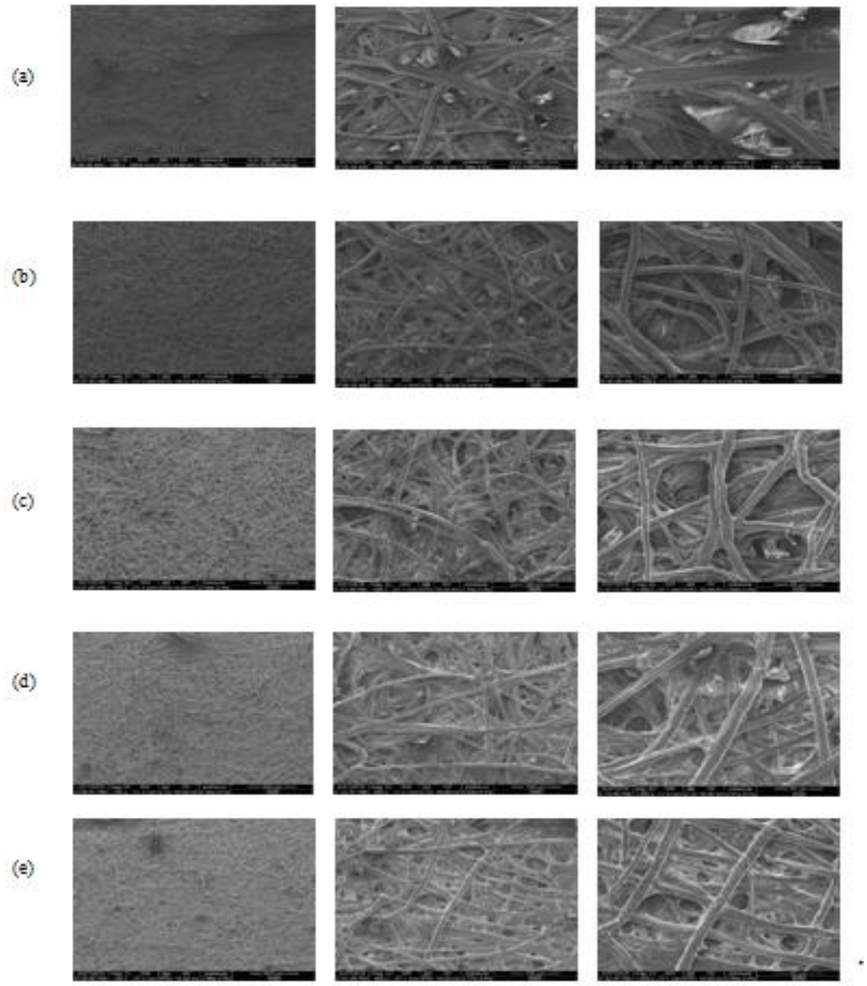

Figure 3: SEM image of kenaf bast fibre paper surface (a) Unbeaten (b) 1000 revolutions beating time (c) 2000 revolutions beating time (d) 3000 revolutions beating time (e) 4000 revolutions beating time

4. Conclusion

As a conclusion, this study proved that pulp beating process up to 4000 revolutions has significant impacts to enhancing physical and mechanical properties of kenaf bast fibre paper. In overall, the paper and pulp samples produced through 4000 beating revolutions showed the best physical and mechanical properties compared to the other beating revolutions. The quality of KBF paper produced at 4000 beating revolutions also in good agreement with commercial OEM oil filter elements. Since the OEM benchmark samples are currently employed for oil filtration in commercial vehicles, this study produced significant baseline data for future process optimisation in order to develop kenaf bast paper as alternative oil filter element for automotive application.

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[17] TAPPI T 227 Freeness of Pulp (Canadian Standard Method)

[18] TAPPI T 248 Laboratory Beating of Pulp (PFI Mill Method)

[19] TAPPI T 402 Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets, and Related Products

[20] TAPPI T 410 Grammage of Paper and Paperboard (Weight Per Unit Area)

[21] TAPPI T 411 Thickness (Caliper) of Paper, Paperboard, and Combined Board

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