EFFECT OF DIFFERENT COOKING TEMPERATURE AND ALKALINITY ON MECHANICAL AND MORPHOLOGICAL PROPERTIES OF COMPOSITE SHEET FROM DURIAN SHELL WASTE FIBRE

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ABSTRACT: Temperature and alkalinity are the critical factors that contribute to the successful of soda pulping. These factors influence the length size and interfibre bonding of the fibre. In this paper, durian (*Durio zibethinus* Murray) shell composite sheet were prepared by conducting chemical pulping through soda method to study the effect of different pulping temperature and % of NaOH on the mechanical and morphological characteristics of durian shell composite sheet. Six sets of composite sheet were produced from six sets of pulping. The pulping processes were conducted at 140, 160 and 170°C with 17, 19 and 21% of active alkali. The mechanical properties of the durian shell composite sheet were analyzed through few standard TAPPI analyses which are tensile, tear, burst, folding endurance and paper bulk thickness. The results show that the highest reading of paper bulk thickness, tensile, tear and burst index, and also folding endurance were achieved at the pulping condition of 170°C with 21% of NaOH with the value of 1.3366 g/cm3, 54.151 NM/g, 6.648 m.Nm2/g, 2.517 k.Pam2/g and 170 no. of fold, respectively. Scanning electron microscopic analysis showed that morphological changes took place depending on the size and arrangement of the fibres in the composites sheet.

KEYWORDS: *Durian Shell; Composite Sheet; Soda Pulping; Cooking Temperature; Alkalinity*

1.0 INTRODUCTION

In recent years, lots of researches have been carried out towards transforming plant waste fibre residues into by-products. Plant waste fibres generally can be defined as lignocellulosic. Agricultural residues, grasses, woods and other plant substances are classified under lignocellulosic materials. The unique characteristics, arrangement and composition of lignocellulose make them suitable for numerous application such as composites [1–5], fuel [6], textiles [7] and paper production [8–12]. The current major uses of hard cellulosic fibres are such as kenaf, bagasse, flax, wheat straw, jute, banana, and pineapple leaf. The increasing interest in introducing degradable, renewable, and inexpensive reinforcement materials which have been environmentally friendly has stimulated the use of cellulose fibres. The low cost, less weight, and density makes the natural fibres an attractive alternative to inorganic or petrochemical-based fibres.

Sheet or paper is almost used by everyone. For the past generations until now, the newspaper industry is one of the industries that contribute to our daily life. Consequently, the demand for paper is expected to increase day by day. Today the finest papers are developed all over the universe, but one disappointing fact is that deforestation causes millions of trees are cut just for the sake of building paper.

An alternative resolution for this problem is to find another material for producing a composition that can benefit us and would create better opportunities in the study of concern. Among all the natural fibre-reinforcing materials, durian shell appears to be a promising material because it is inexpensive, abundantly available and has good mechanical properties. Name of durian (*Durio zibethinus* Murray) comes from Malay word which is "duri" means thorn with adds suffix-an in noun of Malay. The durian naturally exists in South East Asia and usually well-known in many kinds of region's low-lying forests. Basically, durian is commonly cultivated in Malaysia and Thailand with a lot of variety durian type to sustain the distinction of being the most highly prized fruit in the country [13]. Some of aficionados called durian as "King of Fruits". Durian has a tropical family name called Bombacaceae that known to show flowers and pods, with seeds covered with cotton-like fibres. This fruit also is genus of Durio and has 29 species and six of which produce edible fruit. The genus exists in the area of South East Asia with wild durian found in Borneo and Sumatra. The durian shell consists of 9.24 % of moisture content, 4.34 % of ash content, and 6.43 % of fixed carbon [14]. Due to the large plantation area of this yield, there is also a huge waste of its shells after the flesh has been eaten. Based on the statistic carried out by The Department of Agricultural of Malaysia [15], durian plantation is the largest in Malaysia of about 72,391.34 hectares with 210,873.99 metric ton. Therefore, in order to cut the durian shell wastage, the durian shells are utilized as the main material for the sheet and paper production.

Wood comprises two main parts which are lignin and cellulose. The term of cellulose refers to fibrous components of wood that are used to produce pulp and later being transform into paper. Lignin on the other hand is the sticking medium that sticks the wood fibres together. The separation of lignin and cellulose is called pulping process which will reduces the bulk wood form into fibrous mat form [16]. Pulping process can be performing through two methods which are chemical and mechanical pulping.

Chemical pulping involves treating wood chips with chemicals to remove the lignin and hemicellulose, thus separating and cleaning the fibres. Delignification gives the fibres greater flexibility, resulting in a substantially stronger paper (because of greater contact between the fibres in the finished sheet) compared to high-lignin fibres produced by mechanical pulping. Paper strength and durability is gained at the expense of fibre yield. Chemical processes may yield only half the fibre that can be recovered by the use of mechanical pulping techniques. For chemical pulping, there are three methods are namely as kraft, soda and sulphite pulping process.

The soda process is the oldest and simplest pulping process. Besides, it is applicable to leafy and conifer wood, as easily as to non-wood raw materials such as agricultural residues. The procedure uses a sodium hydroxide solution as cooking liquor and provides chemical or semi-chemical pulp, depending on how drastic the operating conditions are. Soda pulping also uses no sulfur compounds and is well characterized in technological terms.

Currently, there is no report on the characteristics analysis of unbleached durian shell composite sheet using soda as the pulping method with various process conditions. The optimum process conditions of pulping needs to be achieved in order to produce the best quality of durian shell pulp and composite sheet. Therefore, this paper presents a detailed investigation on the effect of cooking temperature and alkalinity on the mechanical and morphological properties of unbleached durian shell composite sheet as an alternative for wood-based materials.

2.0 METHODOLOGY

2.1 Preparation of Raw Materials

Raw durian shells are collected from a durian garden in Melaka, Malaysia. After the assembling of the durian, the shell was cut manually to a uniform size of 2 to 3 cm in length and 1.5 cm in thickness as in Figure 1. Then, the durian shell chips were repeatedly washed with tap water to get rid of surface dirt and other unnecessary materials. Next, they were dried in drying oven at 50°C for 24 hours to remove moisture content before it was groomed for the following procedure [17].

Figure 1: Durian shells chips

2.2 Pulping Process

After the drying process, dried durian shell chips need to go the process of pulping to separate cellulose from lignin. The selected pulping process is soda pulping process because it use lignocellulosic as a crude material and the process is milder than sulphite and kraft pulping process. The process was done by using rotary digester machine. The use of sodium hydroxide (NaOH) in making wood pulp is known as soda pulping process [18]. The soda pulping process was carried out at different process conditions with variables of 140, 160 and 180°C of cooking temperature and 17, 19 and 21% of alkalinity as summarized in Table 1. About 300 g (oven-dried) of durian shell chips was placed into the digester vessel. The ratio of durian shell chips to cooking liquor was kept constant which was 1:10 and the duration of cooking was also kept constant at 90 minutes. Once cooked, the unbleached durian shell pulp was washed, screened and centrifuged.

Table 1: Experimental values for dependent variables of pulping process

Run no.	Cooking temperature (°C)	NaOH concentration (%)	Cooking duration (min)	Ratio (Fibre : Liquid)
1	180	21	90	1:10
2	180	17	90	1:10
3	160	21	90	1:10
4	160	17	90	1:10
5	140	21	90	1:10
6	140	17	90	1:10

2.3 Sheet Formation

The produced unbleached durian shell pulps from different pulping process conditions were prepared for sheets formation. The process was made by using a sheet machine (British Handsheet Machine) in accordance to the TAPPI T 205 with a basis weight of 60 g/m^2. These sheets were conditioned at 23 ± 1 °C and 50% relative humidity for 24 hours in accordance to TAPPI T 402 sp-98 [19].

2.4 Sheet Characterization

The sheets produced were tested for the mechanical and morphological analysis. For the mechanical analysis, few analyses were carried out which are tensile index, burst index, tear index, folding endurance, and thickness. All of the analyses were determined according to TAPPI T 494 om-96, TAPPI T 403 om-97, TAPPI T 414 om-98, TAPPI T 423 om-98 and TAPPI T 411 om-97 respectively. The Carl Zeiss Model 1450VP variable pressure scanning electron microscope (SEM) was used in characterizing the surface morphology of the composite sheet surface.

3.0 RESULTS AND DISCUSSION

3.1 Effect of cooking temperature and % active alkali on mechanical properties of durian shell composite sheet

According to Alaejos et al. [10], the time needed to accomplish the operating temperature, was excluded from the pulping time as it was found to have no effect on the final properties of the pulp because it was only a small fraction of the overall time and secondly due to the combined effects of temperature and time, the severity of the treatment was insignificant during the time needed to increase the temperature relative to the treatment that involves operating temperature and cooking times [19]. Therefore, for this experiment, duration of pulping needed to accomplish the operating temperature was set to constant.

Table 2 shows the paper bulk thickness result of durian shell composite sheet at each run of pulping.

Table 2: Paper bulk thickness of durian shell composite sheets

Run no.	1	2	3	4	5	6	Durian shell Soda-Anthraquinone (Soda-AQ) paper [20]
Bulk thickness (g/cm^3)	1.3366	0.8338	0.743	0.7401	0.5698	0.532	0.672

From the table, it shows that the highest bulk thickness was obtained at pulping no. 1 with the value of 1.3366 g/cm^3 which was at the highest temperature (180°C) and highest % of NaOH (21%). This value is higher than the bulk thickness value of soda-AQ pulp of durian shell conducted by Masrol et al. [20] which was 0.672 g/cm^3. This result indicates that the bulk thickness was decreased with the decreasing value of cooking temperature and active alkali.

Figure 2 shows the influence of different pulping conditions on the tensile and tear index of durian shell composite sheets. In order to study the impact of cooking conditions on pulp strength, the tensile and tear index at 3000 PFI revolutions were plotted (Figure 2). The tensile index is significantly affected by the conditions in the pulping process. It demonstrated a decline pattern with the decrement value of cooking temperature and % NaOH. Tensile index is maximum (54.151 NM/g) at pulping run no. 1 with the cooking conditions of 180 °C and 21% NaOH. Pulping run no. 6 (140 °C and 17% NaOH) shows the lowest tensile and tear index with 30.061 NM/g. For tear index, all sets of pulping show a quite similar index. The variation of cooking conditions does not have much significant effect on the tear index. The tear index was also highest at run no. 1 (6.648 m.Nm²/g), with the cooking conditions of 180 °C and 21% NaOH and lowest at pulping run no. 6 (140 °C and 17% NaOH) with the index reading of 4.876 m.Nm²/g.

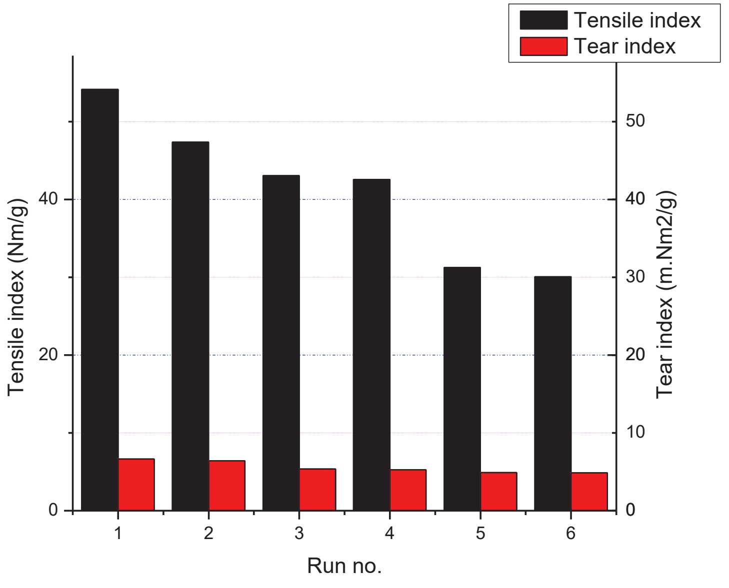

Figure 2: The impact of different cooking conditions on tensile and tear index of durian shell composite sheet

Figure 3 demonstrates the effect of different pulping conditions on the burst index and folding endurance of durian shell composite sheets. The folding endurance is significantly affected by the conditions in the pulping process while it does not has much significant effect on the burst index. From Figure 3, it shows that the highest burst index and folding endurance were also obtained from the pulping run no. 1 with the value of 2.517 k.Pam²/g and 170 no. of fold, respectively. On the other hand, the lowest value of burst index and folding endurance were gained from the pulping run no. 6 with the value of 1.767 k.Pam²/g and 30 no. fold, respectively.

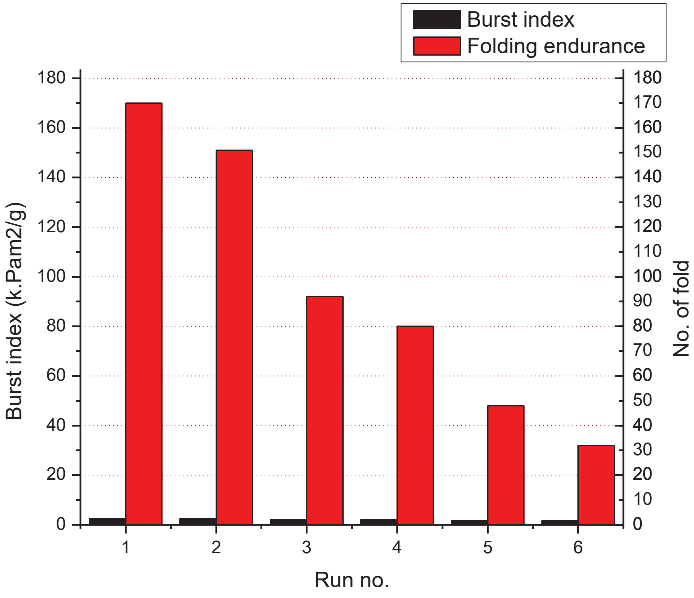

Figure 3: The impact of different cooking conditions on burst index and folding endurance of durian shell composite sheet

3.2 Effect of cooking temperature and % active alkali on surface morphology of composite sheet

Figure 4 shows SEM micrograph of the surface of durian shell composite sheets for all pulping conditions. In Figure 4(a) and 4(b), countless no. of wide and deep voids were found on the entire surface of the composite sheet. The high value of temperature (180°C) with the high % of NaOH (21% and 17%), has made the lignin being removed from the cellulose. There is obviously entanglement and non-uniformity arrangement of fibres on the entire structure of the sheet that lead to the rough and high strength of the sheet. In addition, the minimum lignin that binds between the fibres has caused the morphology (shape and structure) of the fibre can easily being observed.

For Figures 4(c) and 4(d), medium amount of lignin was found on the composite sheet surface. Less voids were found on the entire surface of the composite sheet. The medium value of temperature (160°C) with the % NaOH of 21% and 17% have remove just certain amount of lignin from the fibre cellulose.

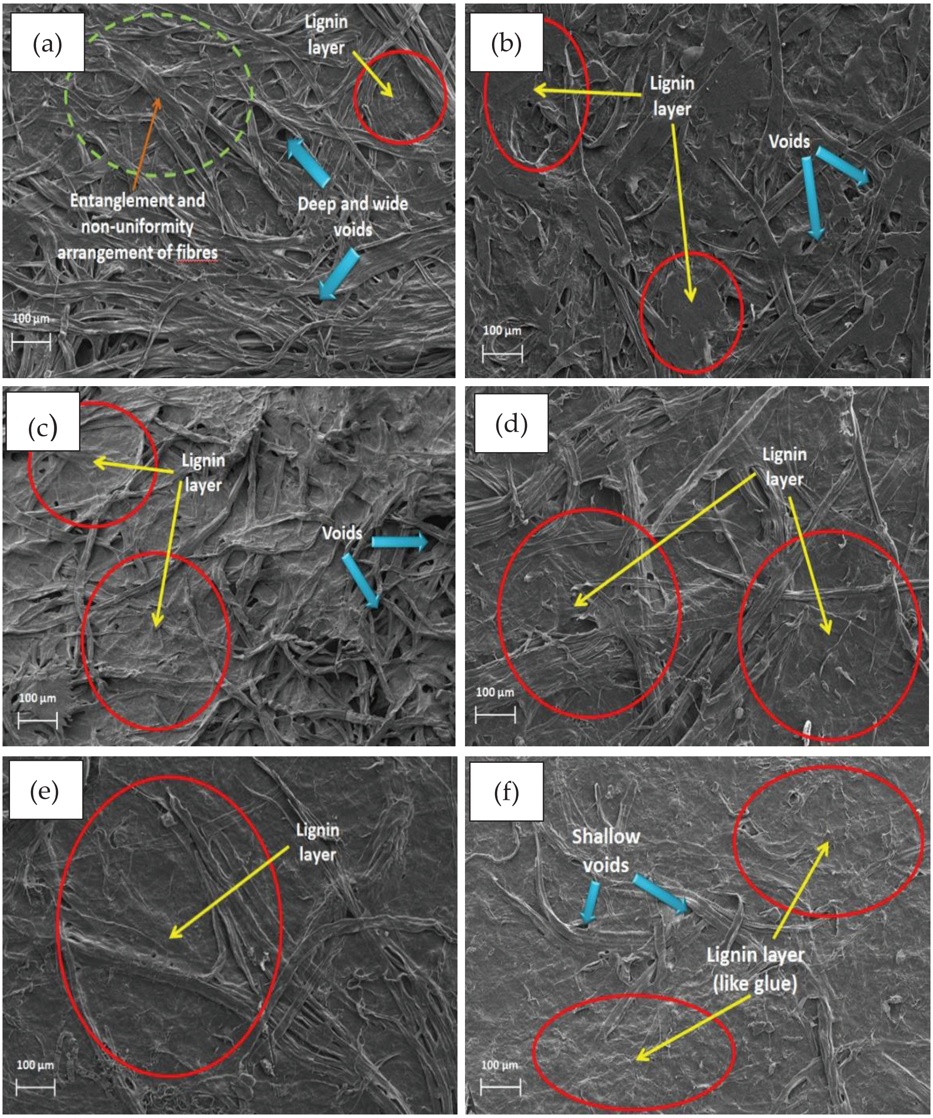

Figure 4: SEM images of durian shell composite sheet at pulping condition of (a) 180°C and 21% NaOH, (b) 180°C and 17%, (c) 160°C and 21%, (d) 160°C and 17%, (e) 140°C and 21% and (f) 140°C and 17% at 100x magnification

On the other hand, Figures 4(e) and 4(f), hoighest amount of lignin was found on the composite sheet surface. Lignin layer has covered most of the entire surface of the sheet therefore it has fewer and shallow voids. The low value of temperature (140°C) and % NaOH (21% and 17%) have remove just less amount of lignin from the fibre cellulose. These result in low mechanical strength of the composite sheet. In addition, it can be seen that the least voids between the fibre-to-fibre bonding were resulted from the arrangement of short fibres that created from the pulping conditions. This makes the surface of the composite sheet in Figures 4(e) and 4(f) smoother than other composite sheet's surfaces.

4.0 CONCLUSION

The investigations on mechanical and morphological characteristics of composite sheet made from durian shell pulp via soda pulping method were successfully achieved. The results show some encouraging potentials of durian shells as a new alternative raw material for packaging application. As the cooking temperature decreases, the mechanical properties of the composite sheet were also decreases. The increment of NaOH percentage has enhanced the interfibre bonding and individual strength of the paper. The highest mechanical properties of the durian shell composite sheet were achieved at the highest cooking temperature of 170°C with the highest % of alkalinity (21% NaOH) with the value of 1.3366 g/cm^3 of paper bulk thickness, 54.151 NM/g of tensile index, 6.648 m.Nm^2/g of tear index, 2.517 k.Pam^2/g of burst index and 170 no. of folding endurance. The results were also supported by the morphological observation on the lignin layer and arrangement of the fibres in the composite sheet.

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