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The Characteristics of Pulp and Paper Made from Top Section of Betong (*Dendrocalamus Asper*) Bamboo by Soda Pulping Method

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Abstract: This research was conducted to assess the potential of Malaysian Betong (*Dendrocalamus Asper*) bamboo as an alternative non-wood based material for papermaking. Top section of Betong bamboo was selected as the raw material for this study. Bamboo pulp was produced according to the Soda pulping method with 25% alkali concentration (NaOH), 7:1 liquor to fibre ratio, 170 C cooking temperature and 3 hours cooking time. Malaysian International Organization for Standardization (MS ISO) and the Technical Association of the Pulp and Paper Industry (TAPPI) were referred to as a standard for all process and characteristics tests. Pulp characteristics have been observed as pulp moisture content (18.45 %), screen yield percentage (20.88 %), pulp drainage time (5.88 s), and Canadian Standard Freeness (CSF) (691.50 ml). For physical characteristics, thickness (578.9µm), grammage (130 gsm), and paper density (0.225 g/cm^3) were observed. Mechanical characteristics are also investigated by tensile index (1.581 Nm/g), tear index (1.817 mN.m^2/g), burst index (1.730 kPa.m^2/g), and folding endurance (1.758). The top section of Malaysian Betong bamboo virgin soda pulp and paper had shown a promising quality as papermaking material. However, more future in-depth investigation is needed to improve the quality of the pulp and paper. This study showed the potential quality of Malaysian Betong bamboo as an alternative non wood-based material for papermaking.

Keywords: Bamboo, Non-Wood, Pulp and Paper, Soda Pulping

1. Introduction

The global pulp and paper industry has been thriving, resulting in a rise in demand for pulp and paper raw materials. Increased pulp and paper production involves extensive tree cutting, which leads to deforestation [1]. It is critical to investigate the environmental effect of paper manufacturing since it has several negative implications for the forest, resulting in a shortage of pulp and paper raw resources.

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As a result, non-wood-based fibres are receiving more attention in order to help alleviate the increasing lack of forest wood supply [2] [3].

The growth pattern of Bamboo is a miracle of nature. Bamboo is estimated to cover approximately 39 million hectares of land worldwide, accounting for 4 to 10% of total forest cover in various nations [4]. According to (Azeez & Orege, 2018) [5], bamboo grows abundantly in Asia, where it contributes up to 65 percent of all bamboo production. Bamboo has a rich history in Asia, where it plays an increasingly important role in terms of environmental, social, and economic advantages. Considering bamboo as a fast growing species [6] and grows so abundantly throughout Asia and Africa's temperate and tropical areas, it comes as no surprise that people will keep developing new applications for it [7] and enhance the utilization efficiency of bamboo resources [8].

Dendrocalamus is a subtropical bamboo species that grows naturally clumpy with strong culm walls and large branches. *Dendrocalamus Asper* has huge woody culms that reach a height of 15-20 m and a diameter of 8-12 cm, with moderately thick walls of 11-20 mm that thin off near the top of the culm. Lower culms may have aerial roots (rootlets) from the node. Culm internodes are 40-50cm in length, pale green in colour, and covered in short brown hairs [9].

Bamboo is largely made up of cellulose, hemicellulose, and lignin, which make up about 90% of the total mass. The average length of bamboo fibre of *Dendrocalamus Asper* is longer than G. Scortechinii, 2,261 µm to 3,734 µm [10]. Because the cooking chemical can penetrate the big capillaries and disseminate into the surrounding tissue, the raw materials for pulping must have long fibres and low silica and lignin content to produce high-quality paper [11]. Paper with longer fibre length will have a greater tearing resistance [12]. Bamboo fibres are an excellent raw material for pulp manufacture. They are finer than wood fibres, contributing to the smoothness and flexibility demanded [13].

Soda pulping is a process of extracting lignin from wood and a variety of annual plants, including bagasse, different straw species, flax, hemp, and bamboo on an industrial scale [14]. Natural lignin is also hydrolytically broken down into tiny particles that are soluble in the highly alkaline cooking chemical [15]. Soda pulping has been used to effectively create a variety of non-wood natural pulps, including Gigantochloa Apus bamboo [16] and Nigerian bamboo [17].

The aim of this study is to produce pulp and paper from the top section of Betong (*Dendrocalamus Asper*) bamboo by using chemical soda pulping method. Moreover, the physical and mechanical characteristics of virgin Betong bamboo soda pulp and paper were investigated. The findings of this research are beneficial to papermaking and the Malaysian bamboo industry.

2. Materials and Methods

The methodology chapter, also known as the materials and methods section, explains all of the data needed to achieve the study's goals.

2.1 Material Preparation

A 3-year-old Betong (*Dendrocalamus Asper*) bamboo culm was harvested from Putuo Village, Kulai, Johor, Malaysia. Using a hand saw machine at Makmal Projek Teknologi Perabot, FTK UTHM Pagoh, the sample was divided into three sections: basal, middle, and top (Figure 1a and 1b). The top piece of the bamboo was then chipped manually, and the outer skins of the bamboo strips were removed (Figure 1c). The bamboo strips were cut into smaller pieces around 10 to 15 mm wide with a hammer and chisel (Figure 1d). The bamboo chips were washed and cleaned to remove any extraneous materials. Then, the chips were naturally dried under the sun for three (3) days and being kept at less than 60 percent relative humidity and aerated on a regular basis to avoid decomposition as stated in (Husna et al., 2014) (Figure 1e).

Figure 1: Raw material preparation: (a) process of cutting bamboo culm, (b) top section of bamboo, (c) chipping process of bamboo strips, (d) drying process in the open air

2.2 Soda Pulping

For soda pulping, 500 g oven dried (o.d.) top piece of Betong bamboo chips (BBC) was used. Table 1 shows the fixed pulping conditions:

Table 1: Example of presenting data using a table

Conditions	Value
Active alkali charge (NaOH)	25%
Liquor: fibre ratio	7:1
Initial Temperature	170 °C
Time to reach 170 °C	60 min
Time at 170 °C	180 min

The purpose of the pulping process was to produce paper pulp from the BBC. The moisture content of the Bamboo specimen must be recorded before any operation can begin, in order to compute the BBC real dry weight.

Next, in the rotary digester, an oven-dry (O.D) weight of bamboo fibres were estimated and weighted before being mixed with sodium hydroxide (NaOH) solution. The rotary digester was preheated for 60 minutes to reach 170 °C before being cooked for 180 minutes. After 3 hours, the pressure valve was opened gently until the atmospheric pressure reduced to 1 atm before the hot fibre was taken out carefully from the rotary digester.

Then, the softened bamboo fibre pulps from the rotary digester were poured inside the hydro pulper with water to flush the excess fibre and the remaining black liquor so that the water murky disappeared. Following the washing procedure, PTI Sommerville Fractionators with a slot size of 0.15 mm, according to TAPPI T-275 standard, took over the screening process. This is to ensure that the fibres collected were fine enough for the next process.

After the screening process, the fibres that were filtered out to the silk net were flushed using a water pipe. Afterward, to remove moisture and water content, the fibre was spun with a Pulp Washing Centrifugal Machine. To distribute the pulps, they were placed in the Commercial Mixer machine. The pulp was also weighted to get the pulp yield percentage. Lastly, the bamboo pulp was kept at 6 °C in the chiller until further handsheet making.

2.3 Preparation of laboratory handsheet

The Technical Association of the Pulp and Paper Industry (TAPPI) T-205 "Forming Handsheets for Physical Tests of Pulp" was used to produce the handsheets. For starters, a specific yield weight is required to produce a paper with a weight of 120 gsm (2.44 g). In the following, the pulp is then disintegrated to separate the pulp uniformly using a disintegrator machine. After that, a hand sheet paper making machine was used to create Betong bamboo handsheet. TAPPI T-227 "Freeness of pulp (Canadian standard technique)" was used to establish the freeness value, while TAPPI T-221 "Drainage Time of Paper Pulp" was used to determine the drainage time. The sheets produced from this process were dried and conditioned for at least 24 hours at temperatures below 25 °C and relative humidity below 65 percent but not below 10 percent, according to TAPPI T-402.

2.3 Physical and Mechanical Characteristics of handsheet

The physical and mechanical properties of 120 gsm Betong bamboo handsheets were evaluated in line with TAPPI and the Malaysian International Organization for Standardization (MS ISO). TAPPI T-220 "Physical Testing of Pulp Handsheets" was used to measure the physical and mechanical properties of these papers in a controlled temperature and humidity environment, as specified in TAPPI T 402 "Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets, and Related Products." MS ISO 536 and TAPPI T-411 were used to conduct the grammage and thickness tests, respectively.

2.3 Image Analysis

A scanning electron microscope was used to examine the surface of the fibre (SEM). Gold-coated paper samples were taped to the specimen mounts with double-sided conductive adhesive tape prior to testing.

3. Results and Discussion

3.1 Pulp Characteristics

The grammage of virgin soda pulp 130-gsm paper made from Betong bamboo was obtained in this study. The paper produced has grammage close to required grammage which is 120 gsm. The moisture content of bamboo pulp was determined using an oven dry method where the result is 18.45 %. Thus, the screen yield of soda bamboo pulp is only 20.88 %. This value is lower than the standard value of chemical pulping which is 40.00-50.00 % [18]. As a result, pulping optimization and alternative pulping methods such as Soda-Anthraquinone and Kraft should be used in this research. The high value of Canadian Standard Freeness (CSF) for bamboo virgin pulp is recorded which is 691.50 ml. This value is confirmed by the fast drainage time which is 5.88 s resulting in a rapid formation of paper sheets.

3.2 Physical Characteristics

Table 1 shows the paper properties for the virgin top section of Betong bamboo pulp that consisted of grammage, thickness and paper bulk density.

Table 1: Physical characteristics of Betong bamboo pulp

Physical Properties	Grammage (g/m^2)	Thickness (µm)	Paper Bulk Density (g/cm^3)
Average	130	578.9	0.225
STDV	-	27.4	0.010

The physical properties were determined to find out the characteristics of paper such as thickness, grammage and paper bulk density. Five spots were measured the thickness of paper to obtain the average thickness of one sheet of paper. Single paper sheet has an average thickness of 578.9 µm. The grammage value was 130 g/m^2 which is close to the real value that is 120 g/m^2. The apparent bulk density was 0.225 g/cm^3.

3.3 Mechanical Characteristics

Table 2 lists the mechanical characteristics of paper, such as tearing, tensile, and bursting index, as well as the folding endurance of the paper sheet from the top section of virgin Betong (*Dendrocalamus Asper*) bamboo.

Table 2: Mechanical properties of Betong bamboo pulp

Mechanical Properties	Tensile Index (N.m/g)	Tearing Index (mN.m^2/g)	Burst Index (kPa.m^2/g)	Folding Endurance
Average	1.581	1.817	1.730	1.758
STDV	0.177	0.207	0.180	0.089

The ultimate tensile strength and maximum elongation of Soda Betong bamboo paper was determined by a tensile test, as well as the relative contributions of individual fibre strength and interfibre bonding. The average for tensile stress and tensile index is 2.62 N and 1.581 N.m/g respectively.

Betong bamboo paper has a tearing index of 1.817 mN.m^2/g and an average tearing force per sheet of 236.158 mN. This proved that long fibre paper is said to be substantially more tearing resistant than paper created with short fibres. Furthermore, raw material fibre length and diameter are linked to a positive impact on a variety of mechanical characteristics of pulp and paper, such as tensile index and tear index [19].

A pressure gauge on the device measures the bursting pressure required to break the paper during the bursting test. The bursting strength and index, respectively, are 224.9 kPa and 1.730 kPa.m^2/g. Tensile breaking strength and bursting strength are closely related, and fibre characteristics and papermaking techniques that improve tensile breaking strength also tend to improve bursting strength [12].

Folding endurance is an empirical test that determines how many folds a paper can withstand before its tensile strength falls below a certain threshold [20]. The number of folding for the paper to rupture is around 52 times and the folding endurance is 1.758.

3.4 Characteristics verification

Table 3 compares the physical and mechanical properties of bamboo pulp and paper based on various studies. The qualities of 3 year old bamboo was studied in the current study and (Chang et al., 2013). In comparison to the yield percentage between both studies, (Chang et al., 2013) revealed a greater percentage yield. An increased lignin concentration in mature bamboo stems might be one of the factors. To accomplish total defibrillation, the level of concentration needed to be increased. The kind and intensity of the pulping process utilised have a significant impact on the yield of pulp recovered from a particular species of wood [24]. In the other comparison, the current studies and (Amsalu Tolessa, 2017) both employed the same concentration of NaOH (25%) in their research. However, the addition of Soda-Anthraquinone (Amsalu Tolessa, 2017) resulted in a higher pulp yield percentage. The pulp yield was improved by pulping bamboo with soda AQ [25].

Aside from that, based on the table, another research from (Husna et al., 2014) discovered a variation in mechanical characteristics. It demonstrates that mechanical properties like tensile index and tearing index have a greater value than the current study's results, which occurred as a result of the beating revolutions used on the pulp in the study. The mechanical properties of pulp were strengthened by the beating revolution due to improved interfibre bonding between the fibres for the paper [26].

Moreover, the top section of Betong bamboo (current study) shows higher folding endurance than the top section of Semantan bamboo paper (Husna et al., 2014). This might be related to the greater alkali content of Betong bamboo paper (25.00 % NaOH) compared to Semantan bamboo (20.00 % NaOH, 0.01 % Anthraquinone). This shows that Betong bamboo paper is suitable for papermaking along with previous research on Semantan bamboo paper.

Table 3: Comparison of Physical and Mechanical Characteristics of bamboo pulp from various research

References	References			
	Current study	(Amsalu Tolessa, 2017) [21]	(Husna et al., 2014) [22]	(Chang et al., 2013) [23]
	- *Dendrocalamus Asper* (Betong) - 3 years old bamboo - Soda Pulping - 25% NaOH charge	- Oxytenanthera Abyssinica - Soda-AQ Pulping - 25% NaOH charge - AQ charge: 0.01%	- Gigantochloa scortechinii (Top Section) - Soda-AQ Pulping, Beating - 20% NaOH charge	- Bambusa Stenostachya - 3 years old bamboo - Soda Pulping - 20% NaOH Charge
Yield Percentage (%)	20.88	42.5	-	38.69±0.30
Freeness (ml)	691.5	-	-	432±5.7
Grammage (gsm)	130	-	-	60
Thickness (μm)	578.9	-	-	-
Density (g/cm^3)	0.225	-	-	2.63±0.042
Tensile Index (N.m/g)	1.581	-	32.54	-
Tearing Index ($mN.m^2/g$)	1.817	-	13.45	206±4.2
Burst Index ($kPa.m^2/g$)	1.730	-	1.54	4.30±0.141
Folding Endurance	1.758	-	0.778	89±13

3.4 Image Analysis (SEM)

The morphology of a Soda virgin pulp and paper from the top section of Betong (*Dendrocalamus Asper*) bamboo was studied by SEM.

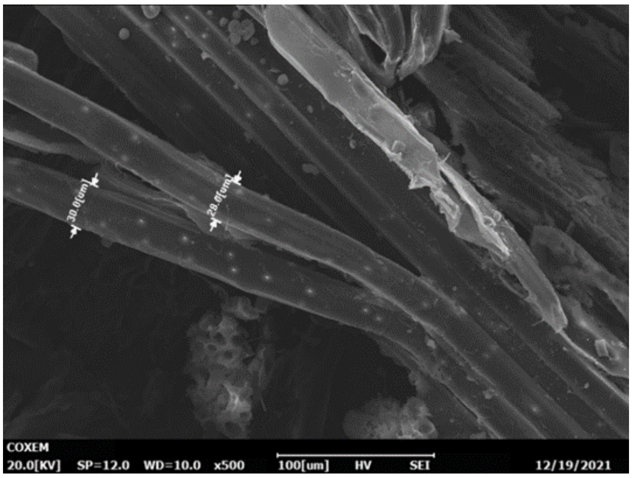

Figure 1: SEM image of top section of Betong (*Dendrocalamus Asper*) bamboo pulp

As shown in Figure 1 the electron micrographs of Betong bamboo pulp fibre surface was presented under magnification of 500 x. According to the SEM results, it has a diameter of 28.0 µm to 30.0 µm which is close to the mean diameter from past research (Siam et al., 2019) which is 19.9 µm - 26.8 µm.

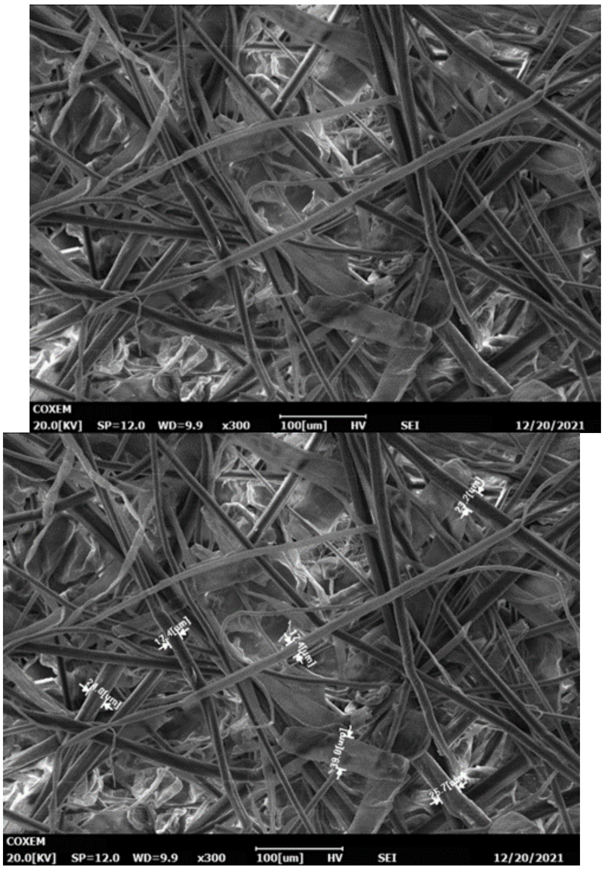

Figure 2: SEM image of top section of Betong (*Dendrocalamus Asper*) bamboo paper with 300x magnification

Figure 2 shows SEM image of surface morphology for the paper hand sheet made from the top section of Soda Betong (*Dendrocalamus Asper*) bamboo with 300x magnification. *D. Asper* fibres, as illustrated in the SEM image of the paper, are a long-fibreed substance. It shows that the fibre has a loose structure and unsmooth surface. It can be seen by the low tensile and tearing index which is greatly affected by the structure of fibre in the paper. In pulping and papermaking, wood with longer fibre length, better flexibility coefficient, and/or lower wall to lumen ratio is well recognized [27]. Since lignin, mineral, and extractive components are removed from plant raw materials during the cooking process of 25% soda pulping, the fibres are shorter and their cross dimensions are decreased [28]. As presented in the Figure 2, the fibre width was reduced to an average of 24.45 µm.

4. Conclusion

Paper making from top section of Betong (*Dendrocalamus Asper*) bamboo by using chemical soda pulping method produced pulp moisture content and screen yield percentage of 18.45 % and 20.88 percent, respectively, in this experiment. The pulp drainage time was 5.882 seconds on average, and the Canadian Standard Freeness (CSF) was 691.5 mL. The thickness, grammage, and bulk density determined from physical characteristics were 578.9 m, 130 gsm, and 0.225 g/cm^3, respectively. Tensile index, tear index, burst index, and folding endurance were all measured at 1.342 Nm/g, 1.817 mN.m^2/g, 1.730 kPa.m^2/g, and 1.758 Nm/g, respectively. Finally, scanning electron micrographs (SEM) micrographs revealed the fibre composition on the paper surface which shown a promising quality as papermaking material. However, more future in-depth investigation is needed to improve the quality of the pulp and paper. This study had shown the potential quality of Malaysian Betong bamboo as another non-wood based material for papermaking.

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