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Characteristic of Pulp and Paper Made From Middle Section of Betong Bamboo (*Dedrocalamus Asper*) by Soda Pulping Method

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Abstract: This study has been carried out to investigate the characteristics of pulp and paper produced from Malaysian bamboo. Middle section of Betong Bamboo (*Dendrocalamus asper*) has been selected as the main raw papermaking material. 120 gsm paper sheet of bamboo has been prepared from unbeaten and unbleached bamboo Soda pulp. The evaluation of the pulping process has been studied based on the chemical. Sodium Hydroxide (NaOH) with dosage of 25.00 % has been used in soda pulping process. The Malaysian International Organization for Standardization (MS ISO) and the Technical Association of the Pulp and Paper Industry (TAPPI) were cited as standards for all process and characteristic tests. Pulp moisture content (20.97 %), screen yield percentage (20.59 %), pulp drainage time (5.772 s), and Canadian Standard Freeness (CSF) have all been observed (725 ml). Thickness (598.90 µm), grammage (126.1 gsm), and paper density (0.212 g/cm^3) were measured as physical characteristics. Tensile index (10.76 Nm/g), tear index (1.32 mN.m^2/g), burst index (1.541 kPa.m^2/g), and folding endurance were also investigated (1.111). This research demonstrated the potential characteristics of middle section of Betong bamboo as a newly explored non-wood based raw material for papermaking.

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

1. Introduction

Paper is widely used nowadays and plays an important role in our daily lives. Despite widespread adoption of paper-free technology, paper remains in high demand in the market. At that time, the demand for wood-based materials increased as a result of the export of the papermaking process, rather than it affecting the ecosystem and causing pollution. Paper has played an important role in everyday life because it is used for printing, packaging, and information dissemination. People are becoming too greedy to cut down trees every day just to process a piece of paper [1].

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1.1 Research Background

Bamboo is a member of the Gramineae family, which includes roughly 90 genera and about 1200 species. Bamboo flowers infrequently and in unpredictable cycles that are still unknown. Bamboo grows prolifically in Asia and South America. In many African, American, and Asian countries, the bamboo plant or grass has cultural and ecological value, providing environmental, social, and economic benefits. Bamboo was chosen as an alternative raw material because it is a fast-growing plant that can be harvested in three to five years and has fiber form and chemical makeup similar to hardwood [2].

In Malaysia, Dendrocalamus asper is an important thick-walled bamboo species. The local name of this species is Buluh Betong. Dendrocalamus Asper, also known as rough bamboo, black bamboo, giant bamboo, or sweet bamboo. This timber bamboo is used as a heavy construction material, and the shoots are eaten as a vegetable. When mature, at the age of 3 to 5 years, this bamboo is tall and has large culms. The culms can grow to heights of 20 to 30 m, with diameters ranging from 8 to 20 cm and internode spacing of 40 cm. The culm has a wall thickness of 6 to 22 mm, and a density of 0.52 to 0.56 g/cm D. asper culm's thick and strong shells make it ideal for use as a building component, as well as the production of furniture, musical instruments, and household appliances [3].

Bamboo pulp is a type of paper pulp, similar to wood pulp, straw pulp, or reed pulp. Bamboo paper can be made from bamboo pulp. Bamboo paper is durable and has a wide range of applications. Bleached bamboo paper is used in the production of offset paper, typing paper, and high-quality culture paper. Unbleached bamboo paper is commonly used in the production of packaging paper. Furthermore, bamboo pulp and wood pulp can be combined to create cable paper, insulation paper, and cement bag paper [4].

The aim of this research is to produce bamboo pulp and paper via soda pulping method from middle section of Betong bamboo. Mechanical and physical characteristics tests will be conducted based on MS ISO and TAPPI standard. This research is conducted to provide information and knowledge about paper making technology that utilize Malaysian bamboo as the new alternative raw material. The findings of this research also contribute to the Malaysian Betong bamboo potential in paper making industry

2. Materials and Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Material Preparation

Dendrocalamus asper (Betong Bamboo) is used as a raw material has been prepared. These are the bamboo species that are commonly commercialized in Malaysia and can be found in the country's tropical forest. A 3-year-old Betong (Dendrocalamus Asper) bamboo culm was harvested from Putuo Village, Kulai, Johor, Malaysia. At Furniture Project Technology Laboratory, UTHM, Betong bamboo was divided into three (3) sections: bottom, middle, and top by using a hand saw machine. After that, the middle section of Betong bamboo was manually chipped, and the outer skins of the bamboo strips were removed. To remove any extraneous materials, the bamboo chips were washed and cleaned. The chips were then naturally dried in the sun for three (3) days before being stored in the lab for seven (7) days. Figure 1 below shows the Betong bamboo that has been prepared. In this study, pulp has been produced from Buluh Betong (Dendrocalamus asper), using the soda pulping method.

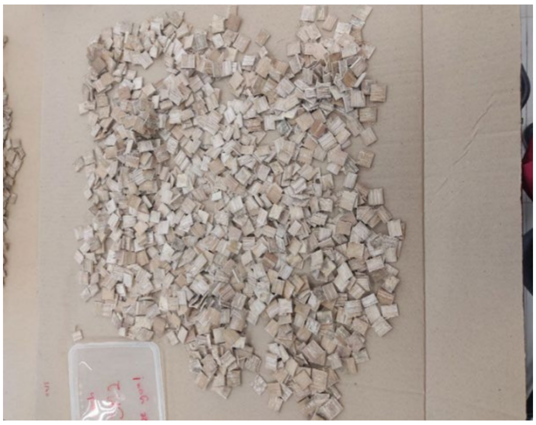


Figure 1: Betong bamboo chips

2.2 Methods

2.2.1 Soda Pulping

The methodology involved few steps in order to produce pulp and paper from Betong bamboo. First, identify the raw materials involved such as Betong bamboo, NaOH, and water. Then, prepare the raw materials according to the condition shown in Table 1.

Table 1: Condition and parameter of soda pulping

Soda pulping condition	Parameter
NaOH	25.00 %
Liquor : fiber ratio	7:1
Initial temperature	170 °C
Time to 170 °C	90 minutes
Time at 170 °C	180 minutes

After being mixed in the rotary digester, the material was cooked for 180 minutes at 170 °C. After 180 minutes, the pulp is removed from the rotary digester and sent to the washing and screening process to remove the black liquor and produce a fine pulp. Following that, the pulp goes through a spin drying process to remove the water. Finally, the pulp was dispersed in order to separate the pulp. Figure 2 shows the rotary digester process.

Figure 2: Rotary digester process

2.2.2 Paper Making

TAPPI T-205 "Forming Hand sheets for Physical Tests of Pulp" has been used to prepare hand sheets. The pulp has been disintegrated first before taken into stock divider. 2 liters of pulp were taken for sample correction and testing. The corrected pulp measurement has been determined and is now being used for the hand sheet paper machine process. The procedure produced paper, which will be pressed and placed in a dry ring. To maintain the paper's quality and standard, the dry ring has been placed in the control room. Figure 3 shows one of the papers making process.

Figure 3: Paper making process

2.3 Pulp Physical Characteristics

2.3.1 Pulp Moisture Content

The moisture content of Betong bamboo was calculated to determine the dry weight. The oven drying method was used to determine the moisture content of the pulp. 2 g of pulp has been placed in a container and baked for 6 hours. The weight of the pulp before and after drying was recorded to determine the weight loss during the oven drying method.

2.3.2 Screen Yield

The screen yield was obtained in the moisture content of the pulp. The Eq. 1 used to find the screen yield percentage. The screen yield obtained by weight of oven dry (OD) minus with weight of starting material (AD)

Screen Yield Percentage (%) = (Weight of Dry Pulp/OD weight starting material) x 100% *Eq.*1

2.3.3 Freeness

The freeness test was conducted according the TAPPI T 227 om-99: Freeness of Pulp (Canadian Standard Method. It is critical to calculate the freeness because it limits the ability of the pulp suspension to drain. The stock divider was used to pour one litre of pulp stock into the chamber. Both the top lid and the air-cock were closed. After that, the bottom lid was swung away. The air-cock was opened to begin the flow. Once the facet discharge is stopped, the degree discharged from the facet gap is recorded. Then, the stock from freeness test were used to produce paper sheet. Eq. 2 shows the formula to calculate freeness value. Figure 4 shows the process of freeness.

Figure 4: CSF Freeness test

Freeness Value (%) = (Weight of freeness after oven (g)/Water level of freeness) x 100 % *Eq.* 2

2.3.4 Pulp Drainage Time

This method describes a procedure for calculating a numerical measure of stock slowness. Drainage time is not always proportional to pulp freeness, as determined by TAPPI T 272 Forming Handsheets for Reflectance Testing of Pulp. As pulp drainage time, the time it took for water to separate from the pulp was recorded.

2.4. Paper Physical Characteristics

2.4.1 Grammage

The basis weight of a paper is determined by deliberating over a sample cut to the basic size for that grade on a "basis weight scale" designed to identify the weight of 500 sheets of the paper being measured. Weight of paper expressed in 'grammage' grams per square meter (gsm or g/m^2). The standard of measuring basis weight is laid out in TAPPI T410 om-08. The weight of a paper sheet per unit area is calculated using the basis weight or grammage. Equation 2.3 shows the formula to calculate the grammage.

Grammage (g/m^2) = (One piece of paper (g)/31 (g)) x 10000 *Eq.* 3

2.4.2 Thickness

For a given basis weight, thickness and size determine how large or dense the paper is. A well-pulp extremely stuffed or loaded paper can have a lower thickness for the same basis weight. Many basic properties such as strength, optical quality and roll quality will be affected by thickness variation. The thickness test will be conducted to measure the distance between the upper surfaces to lower surface of paper with particular conditions. The standards of measuring thickness of the paper is TAPPI T 411 om-10. Figure 5 shows the equipment for thickness test process.

Figure 5: Thickness test process

2.4.3 Bulk Density

The mass per unit volume of paper or board, expressed in grammes per cubic centimetre and determined by the bulking thickness. Normally, this term refers to paper.

2.5 Paper Mechanical Properties

2.5.1 Tensile Test

The maximum stress required to break a strip of paper sheet is defined as tensile strength. Tensile strength testing was performed to determine the ultimate tensile strength and maximum elongation of paper in accordance with MS-ISO 1924-2: 2008, IDT. Tensile strength is a measure of fiber strength, bonding, and length. Tensile strength can be used to predict web breaking resistance during printing or converting. Tensile strength divided by basis weight yields the tensile index, which is expressed as Nm/g. Tensile strength (N/m) and basis weight (g/m^2) are multiplied so that the tensile index (TI) equals (N/m) x (g/m^2) as shown in Eq. 4 . Figure 6 shows the equipment that has been used for tensile test.

$$\text{Tensile Index (Nm/g)} = \text{Average Tensile (N/m)/ Grammage } (g/m^2) \quad \textit{Eq. } 4$$

Figure 6: Tensile test equipment

2.5.2 Tearing Test

T414 om-12 is the TAPPI standard for this type of testing. The tear test determines the resistance of paper to tearing after a small tear has been started. The durability of paper is a measure of its brittleness. The value of tear index is increased by the presence of long wood fiber s. The tear strength of the paper is measured and recorded as the resistance to movement. Tear index is calculated as tear strength per unit basis weight and expressed as $mN/g/m^2$. Eq. 5 shows the formula to calculate the tearing index. The equipment that has been used for tearing test is shown in Figure 7.

$$\text{Tearing Index } (mNm^2/g) = \text{Average Tearing (mN)/ Grammage } (g/m^2) \quad \textit{Eq. } 5$$

Figure 7: Equipment for tearing test

2.5.3 Bursting Test

The burst index is proportional to the bursting strength. The ability to burst has been put to the test. The test was carried out to determine the proclivity of paper seal failure when the package is subjected to various potentials. The bursting index is calculated by dividing the average of bursting by the grammage of paper such as shown in Eq. 6. Figure 8 shows the equipment that has been used in bursting test.

$$\text{Bursting Index (kPa m}^2\text{/g)} = \text{Average Burst (kPa)/ Grammage (g/m}^2\text{)} \quad Eq.\ 6$$

Figure 8: Bursting test equipment

2.5.4 Folding Test

Fold endurance assesses the sturdiness of paper after it has been repeatedly pleated under constant load, determining how many times the paper can be folded-up before it breaks. The folding strength is given as the number of double folds, and the folding endurance is given as the log10 of the number of double folds. TAPPI T511 om-08 describes the standards procedure.

2.6 Scanning Electron Microscope (SEM)

SEM stands for Scanning Electron Microscope. The SEM is a machine that focuses a beam of electrons that are reflected to form an image. The SEM resolution was greater than 1 nm. SEM was used to characterize the paper sample by determining topography (surface features of an object) or morphology, shape, and size of paper fiber. Using conventional SEM techniques, areas ranging in width from about 1 cm to 5 microns were imaged in a scanning mode. The samples have been coated with gold in a low vacuum Ion sputter coater in a layer 150-200 nm thick. Using electro conductive tape, paper has been mounted on specimen holders. The accelerating potential to be used is 20kV. The magnification that has been used x300, and the resolution ranges will be from 50 to 100 nm. The SEM machine is shown in Figure 9.

Figure 9: SEM machine

3. Results

3.1 Bamboo Virgin 120gsm Paper

Figure 10 shows the bamboo virgin paper obtained from this study.

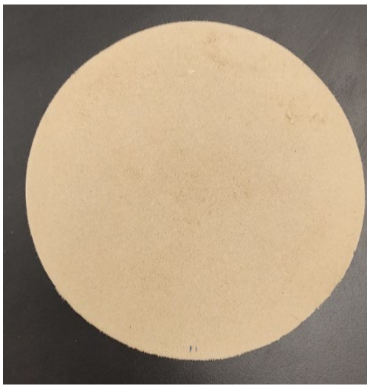


Figure 10: Bamboo virgin paper

3.2 Pulp Physical characteristics

Table 2 shows the value of pulp physical characteristic obtained according to the characteristics tested.

Table 2: Pulp physical characteristics

Characteristic	Value
Moisture content	20.97 %
Screen yield	20.59 %
Freeness	725 ml
Drainage time	5.772 s

3.2.1 Pulp Moisture Content

The moisture content of Betong bamboo has been calculated to find the actual dry weight. The weight of 500 g bamboo chips was prepared for pulp making process. The process was started by obtaining the moisture content of bamboo using oven dry method where the result is 20.97 % was inside 1000 g of bamboo pulp. Moisture content was determined by using oven dry method.

3.2.2 Pulp Screen Yield

The overall yield is calculated after the pulp fiber s have been screened. The percentage of screen yield after soda pulping is 20.59 %, which is suitable for making paper. Because of the screening and washing process, the reading of this yield has dropped.

3.2.3 Freeness

The average freeness obtained from bamboo pulp for sample 1 and 2 is 725 ml. The percentage of freeness value obtained was 0.28 %.

3.2.4 Drainage Time

The drainage time is the time required to produce one sheet of paper. The drainage time was measured for eight samples of paper sheet. The average drainage time was found to be 5.772 s.

3.3 Paper Physical Properties

Physical properties such as thickness, grammage, and paper bulk density were determined to define the structure of the paper. The physical properties of Betong bamboo paper are shown in Table 3. The bulk density of paper obtained from Betong bamboo paper is 0.212 g/cm³. The weight produced is 126.1 gsm. 1 sheet of paper has a thickness of 595.8 µm.

Table 3: Physical properties Betong bamboo paper

Properties	Value
Grammage (gsm)	126.1
Thickness (µm)	595.8
Bulk density (g/cm³)	0.212

3.3.1 Grammage

The weight of a paper sample is calculated per unit area. Gram per square meter (g/m²) or gsm was the unit of grammage. The sample was taken from the tearing test and dried in an oven for 24 hours to determine the grammage value. The grammage value was 126.1 gsm, which is very close to the actual value of 120 gsm.

3.3.2 Thickness

In this test, 8 samples were used to determine the thickness of the paper. To determine the thickness, 5 points were measured. The average thickness of a single sheet of Betong bamboo paper is 595.8 µm

3.3.3 Paper Bulk Density

The bulk density of Betong bamboo paper is 0.212 g/cm³ as shown in Table 3. The increased bulk is primarily due to the thick cell wall thickness, which allows for less surface contact for bonding.

3.4 Paper Mechanical Properties

The mechanical properties of the paper were determined in order to determine its strength. The mechanical properties of Betong bamboo paper are propagated in Table 4 below.

Table 4: Mechanical Properties of Unbleached and Bleached Pulp

Mechanical properties	Tearing Index (mN.m²/g)	Tensile Index (N.m/g)	Burst Index (kPa.m²/g)	Folding
Average	1.32	0.717	1.541	13
SDTV	0.2	0.763	0.145	1.58

3.4.1 Tensile

The average tensile strength and tensile index for this test are 1.36 kN/m and 10.76 N.m/g, respectively. Tensile strength testing was performed to determine the ultimate tensile strength and maximum elongation of Betong bamboo in accordance with TAPPI T494 om-01 and (MS-ISO 1924-2: 2008, IDT).

3.4.2 Tearing

Tearing is the amount of paper elongation that occurs when a specific force is applied to the paper, as well as the amount of strength required to break the paper at a specific distance. The average tearing strength of Betong bamboo paper is 166.89 mN per sheet. The average tearing index for Betong bamboo paper is 1.32 mN.m^2/g. Tearing strength test has been performed based on TAPPI T414 om-98. The paper's short fiber reduces its strength and makes it easier to tear. Inter-fiber bonding only improved tearing strength to a certain point.

3.4.3 Bursting

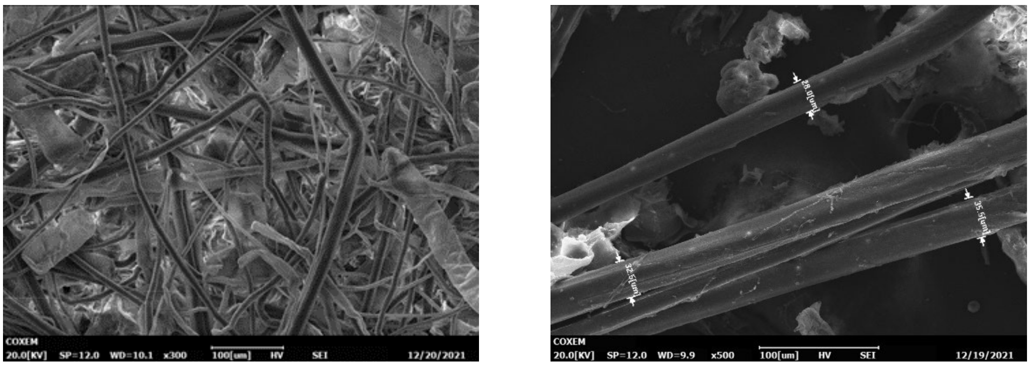
The bursting test area is 730 mm^2, and the clamping force is 1000 kPa. The bursting test average is 194.4 kPa, and the bursting index is 1.541 kPa.m^2 /g, according to Table 4.

3.4.4 Folding

The folding test was performed to assess the paper's ability to withstand multiple folds before collapsing, as well as to assess the paper's deterioration. The average folding result for Betong bamboo paper is 13, with a folding endurance of 1.111.

3.5 Scanning Electron Microscope (SEM)

Scanning Electron Microscopy (SEM) was used to examine the characteristics and properties of unbleached fiber and to provide more detailed information about the sample, such as the surface of the fiber. Figure 11 shows SEM image of Betong bamboo paper surface morphology with 300 x magnification. It can be seen that fiber arrangement and binding were not so uniform. The fiber arrangements were not straight and have some kinks and crimps. Inter-fiber bonding and fiber individual strength are the key features in paper characteristics.



(a) (b)

Figure 11: (a) SEM image of Betong bamboo paper with 300x magnification

(b) SEM image of Betong bamboo fiber with 500x magnification

3.6 Comparison with Previous Study

The influence on the qualities of bamboo paper is compared in Table 5. It is clear that the mechanical properties of bamboo papers were equivalent and produced comparable results. The table below compares the tensile index, tear index, burst index, and double folding ranges of bamboo reported by previous studies. The mechanical properties of bamboo is lower compared to previous study. Double folding result shows better and compatible value compared to previous studies. Therefore, pulp beating treatment, other types of pulping, pulping optimization and dry strength agent (DSA) blending process should be proposed in future observation to enhance the characteristics of Betong Bamboo soda pulp and paper produced in this research.

Table 5: Mechanical characteristics of previous study

Properties	Gigantochla scortechinii (Semantan Bamboo) [2]	Bambusa stenostachya Hackel (Tre Gai bamboo) [3]	Bamboo [4]	Dendrocalamus asper (Betong bamboo)
Tensile index (Nm/g)	87.657	-	48.9	0.717
Tear index ($mN.m^2/g$)	51.965	206	10.1	1.32
Burst index ($kPa.m^2/g$)	37.797	4.30	2.7	1.41
Double folding	2	13	-	13

4. Conclusion

The physical and mechanical properties of Betong bamboo pulp and paper were determined in this study. Betong bamboo pulp was produced using Kraft pulping with a liquid: material ratio of 7:1 and 25 percent NaOH, and it was cooked for 180 minutes at 170 degrees Celsius. The overall procedures followed the Technical Association of the Pulp and Paper Industry (TAPPI) and the Malaysian International Organization for Standardization (MS-ISO). The produced grammage is 126.1 gsm, which is nearly the same as the standard grammage of 120gsm paper. The pulp moisture content and screen yield percentage of Betong bamboo have been determined to be 20.97 % and 20.59 %, respectively. The average pulp drainage time was 5.772 s., and the Canadian Standard Freeness (CSF) was 725 ml. The physical characteristics for Betong bamboo paper obtained for thickness, grammage, and bulk density were 595.8 µm, 126.1 gsm, and 0.212 g/cm^3 respectively. Mechanical properties of Betong bamboo paper were also investigated. Tensile index, tear index, burst index, and folding endurance were also investigated and found to be 10.76 Nm/g, 1.32 $mN.m^2$ /g, 1.541 $kPa.m^2$ /g, and 1.111, respectively. While Scanning Electron Microscopy (SEM) micrographs shows the composition of the fiber on the paper surface.

In conclusion, the objective of the study pulp and paper characteristics of *Dendrocalamus asper* (Betong Bamboo) has been fulfill. According to the findings of this study, 100.00 % of Betong bamboo fiber was suitable for papermaking. Finally, this study demonstrates that Betong bamboo can be used as an alternative wood-based material for papermaking because its properties are compatible with other papermaking materials proposed in previous studies. However, more in-depth studies need to be conducted to enhance the Betong Bamboo virgin pulp and paper characteristics.

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