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Development and Evaluation of Pulp and PaperProperties Using Bambusa Vulgaris

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Abstract: The research aimed to determine the potential value for pulp and paper making using 18% and 22% of active alkali (AA) charge on *Bambusa Vulgaris* (BuluhMinyak). Soda pulping was used for pulping process. The condition of pulping that were use are 18% and 22% AA, with 2 hours cooking time. The pulp, paper production and properties were conducted according to the TAPPI and MS ISO standard. A basis weight of 80 g/m² was used for paper sheet formation. Pulp from 18% AA resulted in 31% of screened yield whereas 22% AA resulted in 38.95%. 18%AA provided the strongest tear and tensile strength index with the value of 8.52 mNm²/g and 2.53 Nm/g, respectively. However, the 18% AA showed lower burst index with the value of 3.71 kPa.m2/g. Meanwhile, 22% AA resulted in tear strength of 8.374 mNm²/g, tensile strength index of 1.48 Nm/g however higher in burst indexwith the value of 4.36 kPa.m²/g. Based on ANOVA analysis, there is a significant difference for tensile and bursting strength except for tearing strength since there is no significant different between both pulping conditions. Based on overall result, it was clear that 22% of AA contributes to best pulp production. Nevertheless, 18% of AA contributes to the best paper properties due to the higher value of tensile and tearstrength. Buluh Minyak fiber with the soda pulping characterization has high potential to be used in the production of paper making industry. The findings of this study will also serve as a disclosure to establish and innovate sustainable paper production while preventing environmental contamination.

Keywords: Active Alkali, Bambusa Vulgaris, Bamboo, Soda Pulping, Pulp, Paper

1. Introduction

Pulp and paper are one of the world's most important industries. The consumer of pulp and paper goods included people from all stage of society. The global demand for paper has risen in recent years. Even if future growth is lowered to 2–3%, existing wood resources may not be enough to meet the growing demand for paper, especially in Asia-Pacific [1]. Recent shortages of wood and environmental

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concerns about deforestation have necessitated the use of alternative raw materials to supplement or replace wood as a source of raw material in the pulp and paper industry. There has been a lot of research and development done on this topic. Malaysia, like most countries, still relies on imported raw materials for pulp and paper production [2].

Bamboo is a massive woody plant that thrives in tropical and subtropical climates. Bamboo growsfast after four to six years of planting. It has the ability to grow up to four feet in a single day. Bamboostalks can be trimmed while still allowing the roots to develop. Each plant can live for up to 75 years, and bamboo takes three to six years to reach harvesting maturity [3]. Furthermore, they have a wide range of physical and chemical qualities that can be used to make a variety of paper grades. As a result, it has become necessary to characterise their pulps and determine their suitability for paper manufacturing [4].

Bambusa Vulgaris (Buluh Minyak) is the best raw material, appropriate for creating medium-high-grade paper, instead of using timbers as a source of natural fiber. Buluh Minyak's fiber structure and content are like coniferous wood for papermaking, according to specialists; the fiber content is high, the fiber is slender and robust, and the fiber length is between broad-leaved and softwood, making it a good raw material for pulping and papermaking [5].

The raw fiber source must be turned into pulp before it can be used to make paper in the paper-making process. This pulp is made from a combination of fibers and chemicals. They can be handled mechanically or chemically. The goal of the pulping process is to remove as much lignin as possible without reducing fiber strength, therefore releasing the fibers, and removing contaminants that cause discoloration and possibly future disintegration [6].

Buluh Minyak uses a soda alkaline pulping procedure throughout the papermaking process to manufacture paper. Soda pulping is a chemical process that uses sodium hydroxide as the cooking chemical to make wood pulp. The qualities of Buluh Minyak-based paper were investigated throughout this investigation. As a result, the newly discovered qualities will be more useful than those discovered in past investigations.

Hence this study is to investigate the percentage of active alkali (AA) charge on Buluh Minyak to determine its potential value for pulp and paper making. The plant was subjected to soda pulping at different operating conditions. The optimum pulp yield was recorded as part of the study. In contrast to this study, the Buluh Minyak undergoes alkaline pulping process to strengthen the mechanical properties of the paper product. It is expected that the percentage of yield will be at a high rate and percentage of rejected yield will be low. The percentage of AA was examined and compared to Analysis of Variance (ANOVA) as statistical analysis with the aim of producing a quality paper that meets the criteria of ISO standard.

2. Materials and Methods

2.1 Materials

The main raw material for this research is 4 years, middle position, Buluh Minyak chip. The Buluh Minyak fibers were then cut to a size of 20 mm to 50 mm using a fiber cutter and stored in uncontrolled condition for later usage (Figure 1). In this study, sodium hydroxide (NaOH) and distilled water were used as the liquor for pulping process.

(a)

(b)

Figure 1: a) Buluh Minyak chips, b) NaOH

2.2 Pulping Methods

Soda pulping was conducted with 15 L rotary digester unit. For each batch of pulping, 500 g oven dried of bamboo sample was used. The fixed pulping conditions for each batch were tabulated in Table 1.

Table 1: The Pulping Condition of Buluh Minyak

Pulping condition	Values
Active alkali (as NaOH based on o.d. fiber), %	18, 22
Liquor to raw material ratio	7:1
Cooking time, h	2
Cooking temperature, ºC	170

Two stages of alkali percentage (18% and 22%) were used in this study in comparing the lower value and upper value of pulping conditions.

The pulp was placed inside a hydra pulper after the pulping process to scatter the fibers into individual fibers. After that, the pulp was thoroughly rinsed under running water to eliminate any remaining liquor from the fibers. The pulp was continuously added into a Sommerville screener with a 0.15 mm slot size to separate the fiber from the rejected or uncooked bamboo, and only those fibers that passed the screener were used in the papermaking process. Then, the screened Buluh Minyak pulp was spin-dried, disintegrated by Hobart mixer and used for paper making as well as their characterization.

2.3 Preparation of laboratory paper sheet making

The laboratory paper (80 g/m²) was made from the resultant pulps using a British handsheet former in accordance with Technical Association of the Pulp and Paper Industry (TAPPI) T 205 sp-02(Forming Handsheets for Physical Tests of Pulp). Meanwhile, the Malaysian Standard Methods were used to evaluate the qualities of the paper (MS ISO). The paper machine was opened prior to paper formation, and the surface of the wire was washed away from clinging fibers with water. The machinewas closed, and water was poured in until it reached half of its capacity. After that, 1000 mL of diluted coir pulp stock was loaded into the paper machine. After that, the slurry was stirred five times with theperforated stirrer. After mixing, the machine's drain cock was opened to release the water that had beensuctioned into it. Three blotting papers were placed on the drained paper when the paper machine was opened. The brass flat couch plate was then placed on the table, with the brass couch roll gently placed in the center. The roll was turned 5 times forward and backward. Then after, the paper was removed from the wire screen, coated with three blotting papers and a metal plate, and pressed for 10 minutes at 275 kPa to remove any remaining water. Thereafter, the two blotters were switched, and the same pressure was applied for another 5 minutes. Following that, each plate with its connected paper was placed in a stack of conventional rings. To keep the edges of the paper from drying out, a heavy metal block was placed on top of the stack of rings. Figure 2 displays the paper formation process.

(a) (b) (c) (d)

Figure 2: a) Pouring Stock into British Handsheet Former, b) Blotting Paper, c) Drained Paper onStandard Rings, d) Weighing Paper Sheet

2.3 Determination of Pulp and Paper Properties

Eight papers were used for testing their physical properties such as Grammage (MS ISO 536: 2001), Thickness (MS ISO 534: 2007), Tensile Strength (MS-ISO 1924-2: 2010), Bursting Strength (MS ISO1974: 1999) and Tearing Strength (MS ISO 1974: 1999). The results were then used to calculate the means and standard deviations of the experiments. The testing was done according to the standard thatwere tabulated in Table 2.

Table 2: Structural and Mechanical Properties

No.	Test	TAPPI / MS ISO
a.	Grammage	MS ISO 536:2001: Paper & Board – Determination of Grammage
b.	Thickness	MS ISO 534:2007: Paper & Board – Determination of Thickness, Density and Specific Volume
c.	Tensile	MS ISO 1924-2: 2010: Paper and Board – Determination of Tensile Properties – Part 2 – Constant Rate of Elongation Method – First Revision (ISO 1924-2: 2008, IDT)
d.	Tearing	MS ISO 1974: 1999: Paper – Determination of Tearing Resistances – Elmendorf Method – Second Revision (ISO 1974: 1990, IDT)
e.	Bursting	MS 1SO 1974: 1999: Paper – Determination of Bursting Strength (ISO 2758: 2001, IDT)

2.4. Statistical analysis

Data on paper properties (apparent density, tear index, burst index and tensile index) were subjected to statistical analysis of variance (ANOVA) using Minitab 21 software. Mean comparisons were performed by Tukey's Group Range Test (TGRT) at $P<0.05$.

3. Results and Discussion

3.1 Pulp Properties

In chemical process pulping, the fibers are released via a chemical reaction that dissolves the lignin that holds the fibers together [6]. The role of NaOH in the cooking of cellulose natural fiber is to dissolve fat and dirt contained in the fiber, making the fiber clean [11]. Table 3 shows the screened yield, rejectyield, and freeness of the pulps derived from the Buluh Minyak using different AA dosage.

Table 3: Pulp Properties of Buluh Minyak

Pulping condition	Screened yield	Rejected yield	Freeness (ml CSF)
18% AA, 2 hours	31%	14.7%	730
22% AA, 2 hours	38.95%	14.36%	710

From the results obtained, the use of a higher concentration of AA factors (18% and 22%) will increase the whole of screened yield percentage as can be seen in Table 3, This amount was significantly increased from 31% to 38.95% with the increasing of 18% and 22% AA concentrations, respectively at the same range of cooking time and ratio. It is reported that pulping of Buluh Minyak in [12] research using 22% soda resulted in 43.8% screened yield and 44.4% reject yield. This situation might be due to at the high concentration of AA, more carbohydrates such as cellulose and hemicelluloses decomposed into cooking liquor which were then removed along with the black liquor which resulted during the carbohydrate degradation of the fiber [12]. Delignification ascended as well, exposing more cellulose to the direct action of the active alkali in the liquor, particularly through the fibers at the surface, resulting in reduced yield and quality pulp.

Freeness of pulp is a measure of precisely how rapidly water can drain from a diluted fiber furnishes suspension. Based on Table 3 results, CSF values varied and were statistically decreased with the increasing of AA concentration from 18% to 22%, respectively. High freeness indicates low fine fiber.

Fine fibers played an important role in the paper produced, in terms of their opacity, and mechanicalproperties such as burst and tensile strength, but not tear strength [13].

3.2 Structural and Strength Properties

Table 4 shows the paper properties for Buluh Minyak pulp that consisted of paper mechanical properties such as tearing, tensile and bursting index of the paper sheet. Tearing index, tensile index and bursting index were the most important characteristics of paper. The mechanical properties with Turkey's Range Grouping are summarized in Table 4. Statistically, some of the results were found to be different between the parameters being assessed.

Table 4: Paper Properties According to ANOVA Analysis

Pulping condition	18% AA, 2 hours	22% AA, 2 hours
Structural properties		
Apparent density (g/cm³)	0.49^{A} (±0.05)	0.38^{B} (±0.02)
Thickness (µm)	339.13 µm^{B} (±33.6)	425.54µm^{A} (±19.11)
Mechanical properties		
Tensile index (N.m/g)	2.53^{A} (±1.13)	1.48^{B} (±0.61)
Tearing index (mN.m²/g)	8.52^{A} (±1.67)	8.37^{A} (±2.82)
Bursting index (kPa.m²/g)	3.71^{B} (±0.37)	4.36^{A} (±0.65)

Apparent density is one of the structural properties of used as predictor of paper strength, since fiber bonding in the paper increases both strength and density. The apparent density can be calculated from the grammage, and thickness of paper produced. The paper sheet has an apparent density value of 0.49g/cm³ for 18% AA and 0.38 g/cm³ for 22%. Essentially, apparent density is a structural parameter thatis used to forecast paper strength since fiber joining in paper improves both strength and density [9]. Itis indeed easy to figure out based on the grammage and thickness of the paper. A fine fiber indicates the apparent density [7]. Due to their huge specific surface area, fine fiber increased sheet consolidation and bonding formation in general. The apparent density value will rise as the active alkali concentration, resulting in increasing surface area for bonding.

Among the test, strength qualities are crucial because they determine the paper's resistance to stresses and printing performance, for example, tensile strength can be utilised as one potential predictor of web break resistance during printing or converting. Figure 2 illustrates the tensile index.

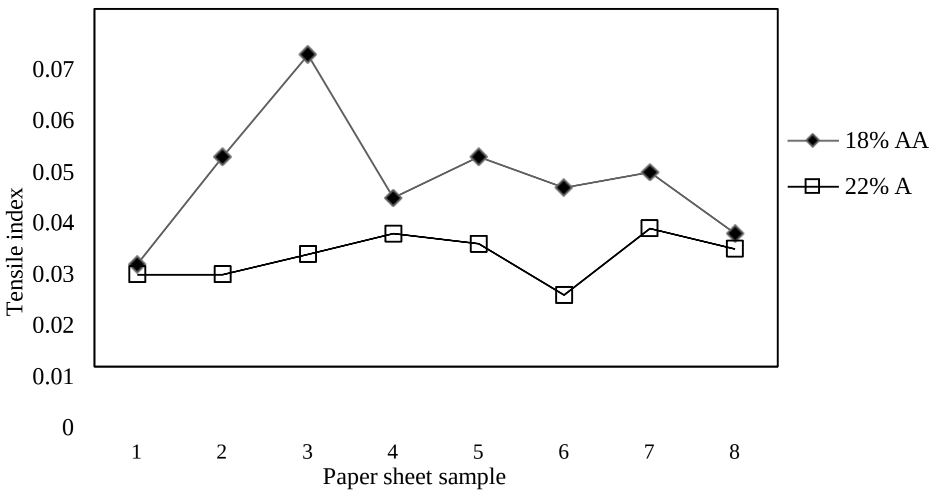

Figure 2: Tensile index of 18% and 22% AA samples.

ANOVA analysis shows that there were significant different between both group of data. 18% AAsamples shows stronger mechanical properties of tensile strength compared to 22% AA samples. This may be due to the carbohydrate degradation in samples 22% AA are higher due to high alkali that were used during the pulping process compared to 18% AA usage. The type of fracture is determined by thebonding strength of the sheet. Fibers are dragged out of the network when the fiber-to-fiber bonds break in a weakly bonded sheet, whereas fibers are pulled out of the network as the fiber-to-fiber bonds break in a well-bonded sheet. In numerous ways, refining enhances the tensile qualities. The fibers become more flexible, making fiber connections easier to form.

The Elmendorf method was employed in the research detailed in this thesis. The test is carried outby creating a fracture in the test piece and pulling the paper apart with a load perpendicular to the face. The tearing is completed by a swinging pendulum, and the energy consumed while the tearing is measured. Figure 3 shows the tearing index for 18% and 22% AA paper sheets sample.

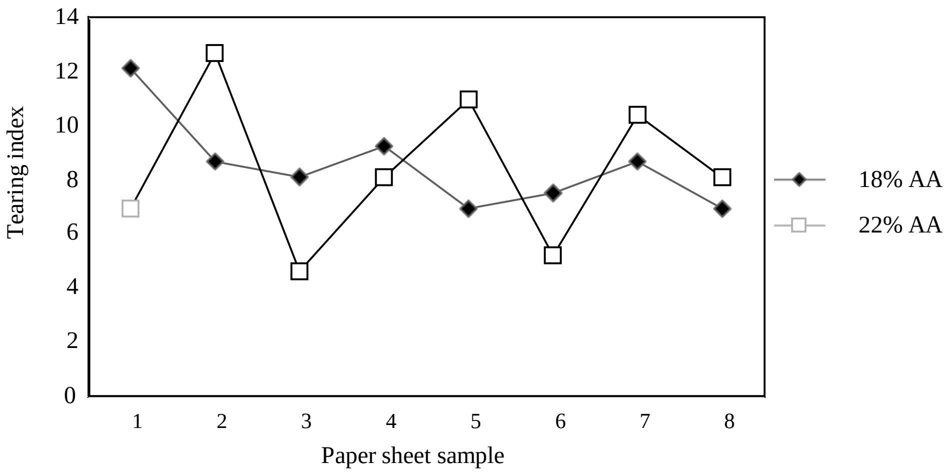

Figure 3: Tearing index of 18% and 22% AA samples.

The tear value rises to a maximum and subsequently declines due to carbohydrate breakdown as the interfiber bonding increases with increasing cooking time and alkali concentration under all conditions. A low degree of interfiber bonding results in a low tear since the fibers break apart quickly and any deterioration of fiber in cooking manifests up drastically in tear loss [7].

The chart shows irregular trend of tearing index since the fiber distribution is uneven, thus lead to unstable tearing spot. The tearing index for 18% AA and 22% AA does not show much different which are 8.523 mN.m²/g and 8.374 mN.m²/g individually. This result was slightly lower than reported by [8], that the tear strength of 3 years old tropical bamboo *Gigantochloa Scortechinii* soda pulp was 13.2 mN.m²/g to 25.2 mN.m²/g at 0 to 10000 revolutions of beating. In this study, ANOVA analysis showsno significant difference for both 18% and 22% AA sample where they share the same group of means.However, the value of tear index for 18% AA is slightly higher than 22% AA.

The bursting index for eight samples of two pulping conditions shows a good correlation between tensile breaking strength and bursting strength, and those fiber properties and papermaking practices that improve tensile breaking strength also tend to improve bursting strength. Figure 4 shows a comparison of different percentages of active alkali on bursting index.

In this study the highest bursting index was for 22% AA samples which reported 4.363 kPa.m²/g. This is quite similar to the studies conducted by [10], it was found that the paper mechanical properties using Semantan bamboo with the optimum condition of 15% alkali charge and 150 ºC of pulping temperature are at 6.94 kPa.m²/g.

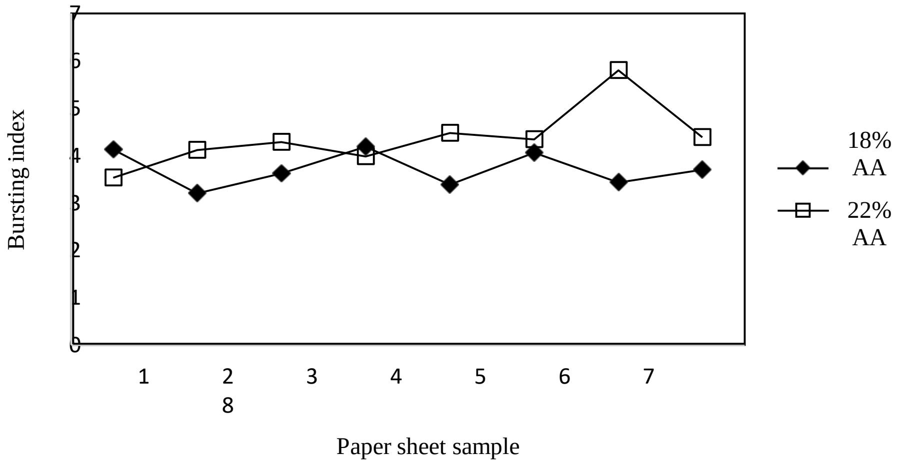

Figure 4: Bursting index of 18% and 22% AA samples.

Fiber parameters may differ at the point of contact between fibers, such as fiber surface, fiber length, fiber stiffness, and fibrillation action, which will impact the distribution of fiber during paper sheet production. When the tensile breaking strength of two papers is equal, usually the one with the greaterstretch has the higher bursting strength. ANOVA analysis shows significant difference between 18% and 22% AA burst index. The inherent bonding ability of a paper's fibers is extremely essential in termsof paper strength. Interfiber bonding quantity and individual fiber strength are two parameters that influence burst and tensile test outcomes.

4. Conclusion

In this study, the percentage of active alkali (AA) charge on Buluh Minyak to determine its potential value for pulp and paper making was examined. Paper properties, pulp properties, significant different, the mechanical strength properties of the Buluh Minyak pulp-based paper are good.

Several conclusions were drawn from the results analysis where the 18% AA documented the best paper properties with the tensile index is 2.53 Nm/g, tear index is 8.523 mN.m²/g, and burst index is 3.714 kPa.m²/g. Meanwhile, sample of 22% shows the result in AA the tensile index is 1.475 Nm/g, tear index is 8.374 mN.m²/g, and burst index is 4.363 kPa.m²/g. Buluh Minyak fiber cooked using Soda pulping have been found affected and increased in terms of their physical properties by the addition of active alkali concentration.

Based on the overall results, it was obvious that 22% of AA contributes to the best pulp production due to better tensile and tear values, however 18% of AA contributes to the best paper properties concerning strength. Except for tearing strength, where there is no significant difference between both pulping conditions, there is a substantial difference between the tensile and bursting tests.

Buluh Minyak fiber has a great potential for usage in the papermaking sector due to its soda pulping characteristics. The outcomes of this study will also be used to build and innovate sustainable paper production while avoiding contamination of the environment.

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