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Dendracalamus Asper (D. Asper) Pulp and Paper-Making Properties Development by Using Soda Pulping

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Abstract: The study sought to ascertain the potential usefulness of an 18% NaOH charge on *D. Asper* (Buluh Betong) for pulp and paper production. The pulping procedure employed soda pulping. The pulping conditions involved utilising the same amount of NaOH and heating for 1.5 h and 2 h, respectively. The production of pulp, paper, and its attributes complied with TAPPI and MS ISO guidelines. The foundation weight for the manufacture of the paper sheets was 120 gsm. 43% of the screened yield was produced by pulp from both conditions. There was no variation between the conditions based on ANOVA analysis regarding the tear, tensile, and bursting index. Both conditions were in the same class of means. Physical characteristics included the following: paper density for 1.5 h was 0.4533 kg/cm^2 and 0.5822 kg/cm^2 for 2 h, thickness for 1.5 h was 245.28 µm and 200.96 µm, and the grammage obtained was 117 gsm for both situations. Investigations into mechanical properties included tensile indexes of 3.43 N.m/g and 4.592 N.m/g, tearing indexes of 3.45 mN.m^2/g and 3.18 mN.m^2/g, and burst indexes of 3.67 kPa.m^2/g and 3.47 kPa.m^2/g, respectively, for 1.5 h and 2 h. The virgin soda pulp and paper from D. Asper bamboo had demonstrated promise as a raw material for manufacturing paper. To enhance the quality of the pulp and paper, additional detailed research will be required in the future. D. Asper fibre has a significant potential for usage in the paper-making sector because of its characteristics for soda pulping. The study's findings will also be used to build and improve sustainable paper production while avoiding environmental contaminating factors.

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

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1. Introduction

The paucity of resources, environmental contamination, and the level of technical equipment have been the three key difficulties that have plagued the development of the paper industry in recent years, and they will continue to do so. The scarcity of raw material resources is the most significant factor, mostly caused by a misalignment between raw materials' structure and fibre resources [1]. The demand for paper around the world has soared in recent years. Even though future growth was decreased to 2–3 %, existing wood resources may not be sufficient to meet the growing demand for paper, particularly in Asia and the Pacific regions [2].

The primary raw materials used in the pulp and papermaking industry can be divided into three categories: wood, non-wood, and non-wood pulp, which account for 63%, 34%, and 3% of global pulp consumption, respectively [3]. Due to increased wood supply competition and gradually growing wood costs, there has been renewed interest in the use of non-wood plants as natural fibre for papermaking in advanced developed countries. The upshot has been the widespread use of bamboo as a non-wood fibre in the pulp and paper industries all over the world, including the United States. This is the most efficient technique for minimizing a reduction in commercial wood prices while also decreasing illegal logger deforestation and degradation of natural resources [3].

Dendracalamus asper (D. Asper), often known as Giant Bamboo or Rough Bamboo, is an evergreen plant native to Southeast Asia that grows in big, dense clumps. It can reach a height of 20 meters and a diameter of 12 centimetres. Fine silky brown hairs cover the younger plants. The nodes are enlarged, with many aerial roots on the younger nodes and branches on the intermediate and upper nodes. It is commonly grown for its highly prized culms, used as building materials, and edible shoots. The culm's upper internodes are used as water containers or to collect juice tapped from the palm inflorescence. Rhizomes, culms, and branch cuttings can all be used to grow them [4]

The pulp is made from wood, non-wood, or other lignocellulosic materials that have been physically and/or chemically broken down to liberate (more or less) distinct fibres that can be distributed in water and reformed into a web. Chemically semi-chemical, chemi-mechanical, and mechanical pulping are the four types of pulping processes. These are listed in order of decreasing reliance on chemical activity while increasing the mechanical energy necessary to separate fibres. On the other hand, chemical pulping methods rely entirely on physical action to separate fibres, whereas mechanical pulping methods do not. Chemical action destroys and solubilizes components of the wood, mainly lignin and hemicelluloses, therefore the more chemicals employed, the lower the yield and lignin content. On the other hand, chemical pulping, produces individual fibres that are not cut and strong papers because the lignin, which interferes with fibre hydrogen bonding, is largely removed. The delignification technology used in the alkaline pulping of wood products is now used in cooking non-wood fibres. Alkaline cooking, in general, necessitates the use of cooking agents such as NaOH, Na2CO3, and others [3].

The purpose of this project is to develop pulp and paper from D. asper using chemical soda pulping. The mill underwent soda pulping under various operational circumstances. The experiment also includes documenting the pulp yield and rejected yield. The different cooking durations were examined and compared using Analysis of Variance (ANOVA) as a statistical analysis to produce a high-quality paper that complies with ISO standards. The physical and mechanical qualities of the pulp and paper from D. Asper were also evaluated. The research's conclusions are advantageous to both the Malaysian bamboo industry and the papermaking industry.

2. Materials and Methods

The D. Asper chip, which is in the middle and top position, is the key raw material for this study. D. Asper fibres were cut using a fibre cutter and the remaining was kept in uncontrolled conditions for later use as shown in Figure 3.1. Chemical composition analysis with sodium hydroxide (NaOH) and distilled water was employed in this investigation. This D. Asper was harvested from Putuo Village, Kulai, Johor, Malaysia.

2.1 Materials preparation

The D. Asper chip, which is in the middle and top position, is the key raw material for this study. D. Asper fibres were cut using a fibre cutter and the remaining was kept in uncontrolled conditions for later use as shown in Figure 1. Chemical composition analysis with sodium hydroxide (NaOH) and distilled water was employed in this investigation.

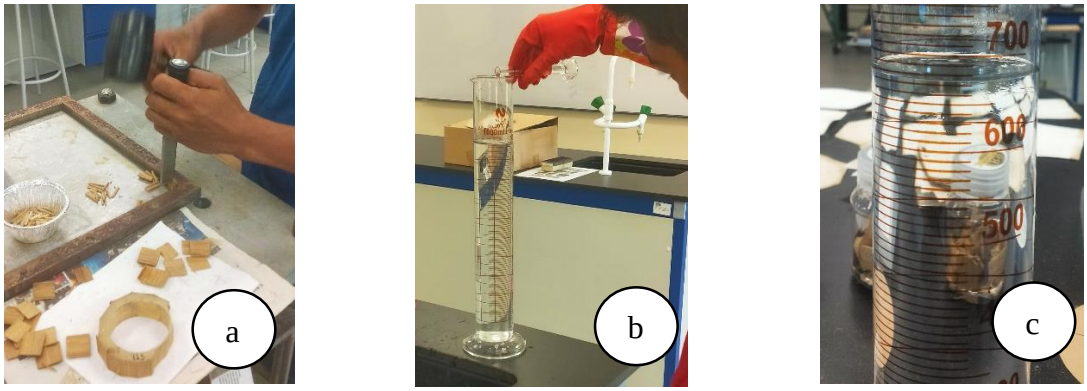

Figure 1: a) Cut bamboo into bamboo chips, b) Pour NaOH into the beaker, c) NaOH level inside the beaker.

2.2 Soda Pulping

It is crucial to keep peeling responses to a minimum during the pulping process so that all pulp cooks uniformly at the same time. Furthermore, sufficient active alkali must be present throughout the cooking procedure, as lignin must be eliminated as much as possible without causing pulp damage [5].

Based on prior research conducted by Chang *et al.* [6] using Bambusa stenostachya, Mohd Hassan *et al* [7] using Semantan bamboo, and Rehman *et al.* [8] using green buttonwood, the active alkali values of 18 %, 20 %, and 22 % were chosen. Instead of using those 3 active alkali values, this experiment will undergo only by using one condition that was 18% of NaOH dosage. Table 1 illustrates the pulping condition.

Table 1: Pulping Condition

Pulping condition	Values
NaOH (active alkali), %	18%
Liquor to raw material ratio	7:1 ratio
Cooking time, h	1.5 and 2.0
Cooking temperature, ℃	170

The percentage of NaOH concentration, cooking temperature, time to attain cooking temperature, and the ratio of liquor to raw materials were all kept constant throughout all the trials. The hot-softened fibres were dissolved by a hydro pulper for 10 minutes after the pulping process, and then completely cleaned with fresh water. Before it was used in the papermaking process, the pulp had to be screened. Cooked bamboo chips were sent through a screening machine to produce a screened yield. Only the right-sized fibres can pass through the screen plate, leaving rejected or bigger fibres on the plate. To estimate the screened reject and screened yield, disiThe scarcity of raw material resources is the most significant factor, art mixer was then used to spin-dry and disintegrate the screened yield. On an oven-drying material basis, screened yield and screened rejections were calculated.

The moisture content of D. Asper fibre was determined first using the oven drying (OD) method, as prescribed by Malaysian Standard MS ISO 287: 1985, IDT. To eliminate moisture from two (2) sets of bamboo chips, bake them in the oven for two hours at 105°C. After that, the chips are placed in desiccators. After then, the weights of the containers were tallied. D. Asper fibres weigh 2 g in each set. In a conventional oven, both sets of D. Asper fibres were dried for a few hours at 105°C. D. Asper fibre moisture content is measured by dividing the weight of the fibres air-dried by the weight of the fibres after oven drying.

2.3 Determination of Pulp Yield and Reject Yield

The hot-softened fibres were dissolved by a hydro pulper for 10 minutes after the pulping process, and then completely cleaned with fresh water. Before it was used in the papermaking process, the pulp had to be screened. Cooked bamboo chips were sent through a screening machine to produce a screened yield. In Figure 2 (b) and (d), only the right-sized fibres can pass through the screen plate, leaving rejected or bigger fires on the plate. To estimate the screened reject and screened yield, disintegrated pulps were screened in a Sommerville screener with a slot width of 0.15 mm. In Figure 2 (c), a Hobart mixer was then used to spin-dry and disintegrate the screened yield. On an oven-drying material basis, screened yield and screened rejections were calculated.

The pulp disintegrator built with TAPPI T-205 and MS ISO 5263 was used in this procedure, as shown in Figure 2.

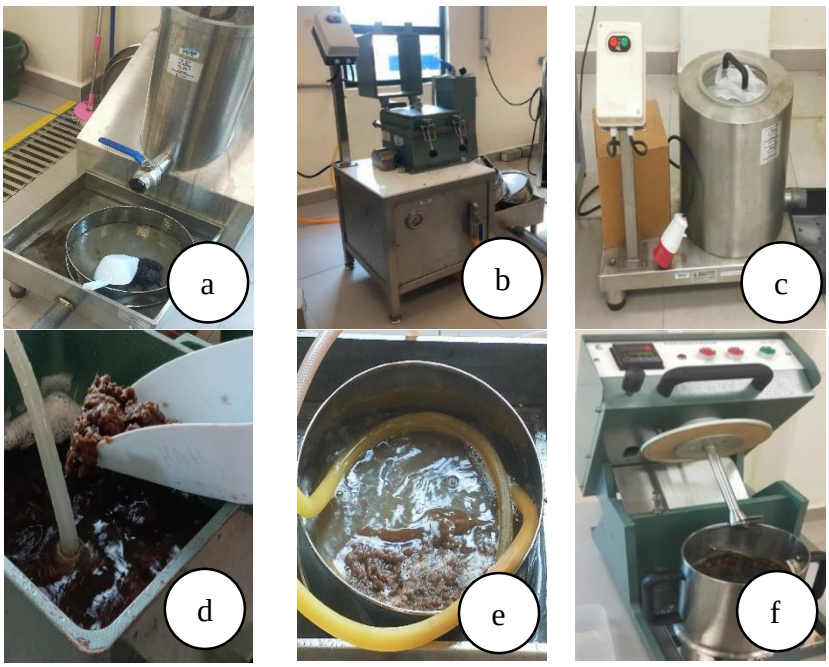

Figure 2: For pulping process a) Hydra Pulper, (2008, India);(b) Sommerville Screener (UEC-2023, India); (c) Hobart Mixer; (d) Pouring pulp into the Sommerville Screener, (e) Screened pulp; and (f) Pulp Disintegrator (UEC-2008, India)

2.4 Formation of Paper Handsheet

Using a British Paper Sheet Former, a 120 gsm paper sheet was formed from the generated pulps in line with TAPPI T 205 sp-02 (Forming Paper sheets for Physical Tests of Pulp). Prior to paper production, the paper machine was opened, and the surface of the wire was cleansed of sticking fibres with water. The machine is shut down, and water is injected into it until it reaches half capacity. The 1000 millilitres of diluted pulp stock will next be poured into the paper machine. The slurry will then be mixed with the perforated stirred, which was pushed up and down five times quickly.

The drain cock on the machine was released after mixing to discharge the water that had been suctioned into it. When the Paper Sheet Machine is opened, blotting sheets were placed on the drained paper. Following that, the brass flat couch plate was set on the table, with the brass couch roll gently placed in the centre. A few times, the roll is spun forward and backwards. After that, the paper was removed from the wire screen and pressed for 10 minutes using blotting papers and a metal plate to remove any leftover water. After that, a different blotter was used, and the same pressure was applied for a few minutes more. The freeness of the pulp was determined using a Lorentzen and Wettre freeness tester and the Canadian Standard Freeness (CSF) according to TAPPI T 227 om-99 (L&W, USA). The machine that was used on creating the paper sheet can be seen in Figure 3.

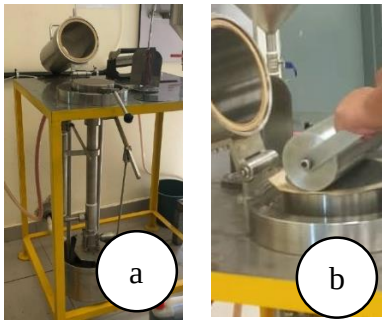

Figure 3: a) British Handsheet Former (UEC 2005B, India), b) Using a roller to press handsheet

2.5 Determination of Structural Properties

The weight of a paper sample per unit area is measured in grammes per square metre (gsm) and is stated in grammes per square metre (gsm). In this investigation, the grammage was evaluated by weighing the sample from the tearing test on an o.d. basis according to MS ISO 287: 1985, IDT. Bulking thickness (Bt), commonly known as calliper thickness, is the thickness of one sheet of paper. When two parallel metal faces are subjected to sustained pressure, the distance between them is called bulking thickness. The apparent density, on the other hand, is the volume per unit mass and is measured in grammes per cubic centimetre. Although it also depends on the fibre structure of the raw material, the cooking process, and the pulp refining level, the density of the paper sheet is another crucial factor that affects many other qualities [9]. TAPPI T411 and MS ISO 534 were used to determine the thickness of the paper using the precision micrometre illustrated in Figure 4.

Figure 4: Precision Micrometer (Model No 46-6, Amityville N.Y. U.S.A.)

2.6 Determination of Paper Mechanical Properties

MS-ISO 1924-2: 2008, IDT to analyse the tensile strength of a test sample using a Horizontal Tensile Tester that offers a constant rate of elongation (Paper and Board - Determination of Tensile Properties - Part2: Constant Rate of Elongation Method). A tear test is a test that determines how resistant a sample is to tear. A common method for starting the controlled tear is to apply a certain tension load to a sample that has been prepared with a cut, slit, or notch. The sample will subsequently be secured using pneumatic clamps. The tearing resistance reading was then automatically determined by the tearing tester. MS ISO 1974: 1990, IDT (Paper- Determination of Tearing Resistance (Elmendorf Method)) was used to conduct the test. The strength of different types of paper and paperboard is determined by their bursting strength. This aspect of the paper is influenced by a variety of factors, including fibre type, formation, chemicals, and basic weight. To improve it, long fibre, wet and dry strength additions, and size compounds are all used. As refining advances, bursting properties improve due to improved fibre-to-fibre bonding. In contrast, increased filler components, secondary fibre, and dried pulp reduce it. Figure 5 shows machines used for paper mechanical testing.

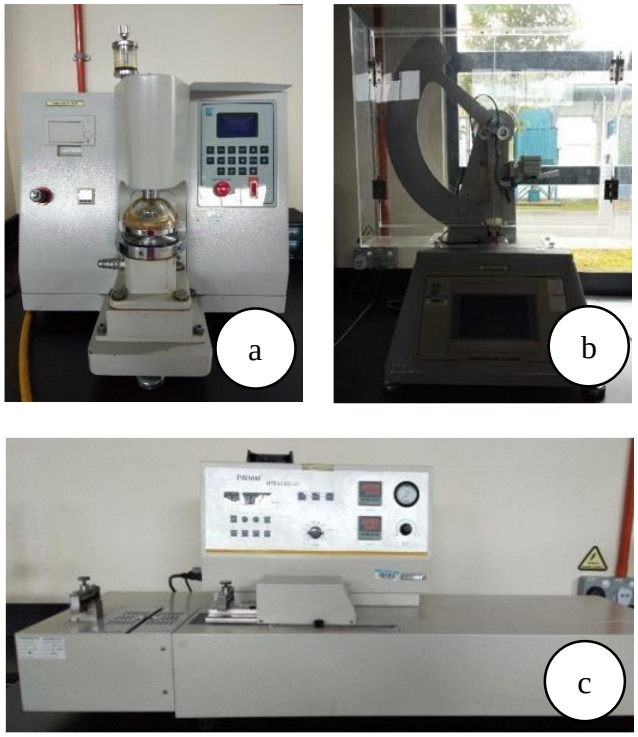

Figure 5: a) Bursting Strength Tester (GT-130600760, Taiwan), b) Elmendorf Tear Tester (TC-140701313, Taiwan), c) Horizontal Tensile Tester (Model XLW Series, China)

2.7 Method of Statistical Analysis

ANOVA was used to see if there is a significant difference between the factor variable (various percentages of NaOH) and the response variable (different percentages of NaOH) (pulp and paper properties). The response variables for pulp qualities were total yield, screened yield, reject yield and CSF. In the meantime, the paper properties study will look into characteristics including thickness, apparent density, tear index, burst index, and tensile index. Using Minitab 21 software, the index of each test was compared to Turkey's range grouping ($p>0.05$)

2.8 SEM

One of the popular techniques for visualising the microstructure and morphology of materials is the scanning electron microscope (SEM). In SEM, a low-energy electron beam is transmitted to the material and scans the sample's surface. As the beam approaches and enters the material, several interactions take place that results in the emission of photons and electrons from or close to the sample surface [10]. Figure 6 shows the SEM machine at the FKMP laboratory.

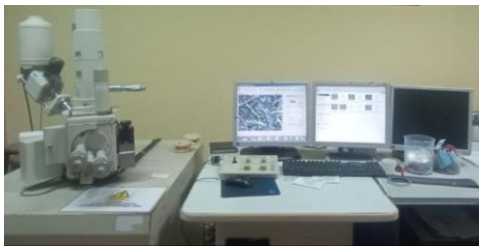

Figure 6: SEM machine (Ultra Plus, 2009)

3. Results and Discussion

This chapter contains the results of the experiment that was performed, followed by a discussion of the results. The qualities of paper made from D. Asper bamboo were investigated in the study. The testing during the trials, as reported in the preceding chapter, used standards from the Technical Association for Pulp and Paper Industry (TAPI) and the American Society for Testing and Materials (ASTM) (TAPPI). The findings and the results were discussed at the same time, and the findings on all research topics were compared to what was available in the literature.

The paper's tensile strength, burst index and tear index are compared to see the difference between the control and alkaline-treated samples. The results showed that the paper created from the treated fibres has a higher strength than that of the untreated control [11]. This increased strength is related to the higher lignin removal achieved during the alkali treatment. The paper's tear index was lower in the treated samples than in the untreated control. This indicates that the alkali treatment has impacted the fibres' flexibility and has resulted in a softer paper.

3.1 Pulp Properties Analysis

It was shown that the optimum NaOH dose of 18% to increase pulp production was constant between 1.5 hours and 2 hours of cooking. It was 43% screened-yield pulp produce. In the meantime, it was noted in the study by Ainun *et al.* [12] that bamboo produces between 40% and 50% pulp. Table 2 displays the pulps' total yield, screened yield, reject yield, and freeness when the same amount of NaOH was used but different cooking periods were used.

Table 2: Screened yield, reject yield and freeness

Pulping conditions	Screened yield (%)	Reject yield (%)	Freeness (ml)
18% NaOH, 1.5 hours	43	2.4	713.33
18% NaOH, 2.0 hours	43	0.65	723.33

Based on the data above, it appears that the pulping conditions affected the yield and freeness of the pulp. In the first set of conditions, the screened yield was 43%, while the reject yield was 2.4%. This means that 43% of the pulp was usable, while 2.4% was rejected. The freeness, measured in millilitres, was 713.3. In the second set of conditions, the screened yield was also 43%, but the reject yield was significantly lower at 0.65%. The freeness increased slightly to 723.33 ml. Overall, it seems that increasing the pulping time from 1.5 hours to 2.0 hours resulted in a lower reject yield and slightly higher freeness. Based Rehman *et al*. [8] demonstrates the importance of pulping conditions when working with Conocarpus erectus (green buttonwood) wastepaper. As the alkali concentration increased from 17% to 23%, there was a significant increase in screened pulp output from 32.56 to 44.13 %, as well as a decrease in reject yield from 22.90 to 4.23 %. It is important for paper manufacturers and other industries that use Conocarpus erectus wastepaper to take into account these findings when determining the best pulping conditions for their applications.

3.2 Paper Properties Analysis

Table 3 provides a summary of the findings on the structural and strength characteristics of paper from Dendracalamus Asper.

Table 3: Paper properties analysis

Pulping condition	18% NaOH, 1.5 hours	18% NaOH, 2 hours
Structural properties		
Apparent density (kg/cm^3)	0.25^A	0.20^A
	(± 0.02)	(± 0.07)
Thickness (μm)	245.28^A	201.0^A
	(± 15.89)	(± 67.9)
Mechanical properties		
Bursting index (kPa.m^2/g)	3.38^A	3.32^A
	(± 0.35)	(± 0.29)
Tearing index (mN.m^2/g)	3.45^A	3.18^A
	(± 0.57)	(± 0.472)
Tensile index (N.m/g)	3.43^A	4.59^A
	(± 2.28)	(± 4.44)

The mechanical properties of the pulp include its bursting index, which is a measure of the resistance of the material to rupture when subjected to pressure; its tearing index, which is a measure of the resistance of the material to tearing when subjected to a force perpendicular to the material's surface; and its tensile index, which is a measure of the resistance of the material to breaking or tearing when subjected to a tensile force. The results indicate that altering the pulping combination parameters will affect the characteristics of D. Asper pulp and paper, as indicated in Table 3.

3.3 Structural properties analysis

The experiment in this study aims to obtain the typical basic weight of 120 gsm. For a paper sample that was cooked for 1.5 hours, the sample's average weight was 2.834 g, and the average area was 203.58 cm^2. While the sample's average weight for two hours of cooking paper is 2.38 g and its average size was 203.61 cm^2., respectively. When the average weight is divided by the surface area of the paper mould, the grammage is revealed. it appears that the grammage is approximately 120 for both cases of 18% NaOH with 1.5 hours and 2 hours.

Depending on the cooking duration and NaOH concentration, the apparent density of the paper that was created varied. Samples cooked for 1.5 h with 18% NaOH had an apparent density of 0.2453 g/cm^3, whereas those cooked for 2 h with 18% NaOH had an apparent density of 0.2010 g/cm^3. According to an ANOVA study, there was a substantial difference between these two circumstances.

3.4 Mechanical Properties Analysis

The results of the ANOVA analysis in Figure 7 reveal that the two sets of data were not significantly different. In comparison to 18% NaOH with a cooking time of 2 h, 18% NaOH with a cooking time of 1.5 h was slightly higher about 1.16 kNm/g mechanical qualities of tensile strength. This can be a result of the samples' carbohydrate breakdown. Due to longer cooking times during the pulping process than in the 1.5 h cooking time sample, the 2 h cooking time sample has a greater cooking time. The maximum

value of the tensile index for the 1.5 h condition was 0.65 kNm/g, while the minimum value of the tensile index for the 2 h condition was 1.45 kNm/g, the maximum load that the sample could support without breaking when stretched.

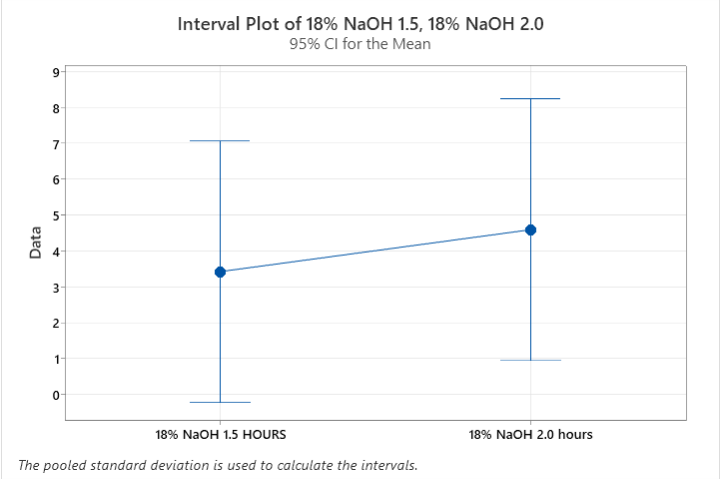

Figure 7: Standard deviation of tensile index for both conditions

Based on Khair & Masrol [13], produced a paper with a dosage only using 25% of NaOH obtained at 1.581 Nm/g for this tensile testing. These results suggest that the 1.5 h condition had a lower tensile index than the 2 h condition, indicating that it was weaker and less able to support a large load before breaking. This could be due to the fact that the sample was exposed to the NaOH for a shorter time, resulting in less cross-linking of the polymers and thus a lower tensile index. The longer 2 h condition had a higher tensile index, indicating that the sample had been exposed to the NaOH for a longer period of time and had more cross-linking of the polymers, resulting in a higher tensile index. The tearing index for 18% NaOH cooked for 1.5 hours and 18% NaOH cooked for 2 hours, respectively, shows no variation and is 3.45 $mN.m^2/g$ and 3.38 $mN.m^2/g$

Figure 8 illustrates this by showing a decline in tear index with varying cooking times. Due to the unequal fibre distribution that results in unstable ripping locations, the chart illustrates the tearing index's erratic trend.

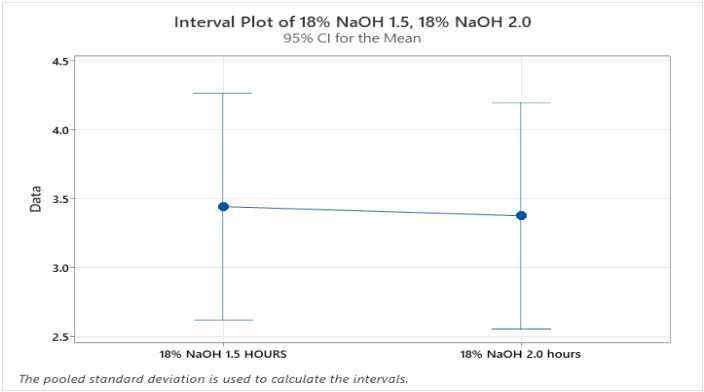

Figure 8: Standard Deviation of tearing index for both conditions

The tearing index for 18% NaOH cooked for 1.5 h and 18% NaOH cooked for 2 h, respectively, shows no variation and is 3.45 mN.m^2/g and 3.38 mN.m^2/g. Based on data achieved by Khair & Masrol [13], the research was charged with 25% NaOH, the tearing index of D. Asper paper is 1.817 mN.m^2/g, and the average tearing force per sheet is 236.158 mN. Besides, research conducted by Mohd Hassan *et al* [7], the paper tearing index employing Semantan Bamboo obtained 12.72 mN.m^2/g.

The bursting index for eight samples of two pulping settings is displayed in Figure 9.

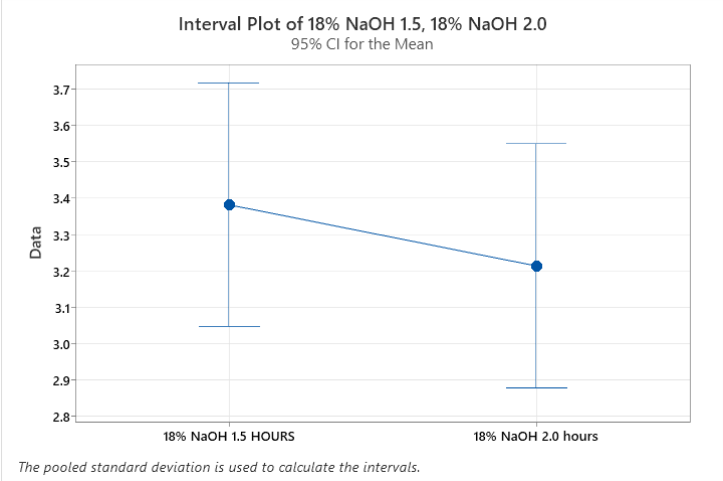

Figure 9: Standard deviation of bursting index for both conditions

ANOVA analysis in Figure 9, reveals a sizable difference between the burst index situations. The average value determined by ANOVA analysis reveals paper sheet samples for 18% NaOH with 1.5 h of cooking time measured at 3.39 kPa.m^2g and for 18% NaOH with 2 h of cooking time measured at 3.216 kPa.m^{2}g. This result is fairly comparable to that of Ainun *et al* [12], who found that the burst index of an active alkali charge of 18% on bamboo gigantochloa scorthechinii kraft showed 2.76 kPa.m^{2}g and 2.80 kPa.m^{2}g, respectively, for untreated and treated fibres paper samples.

In comparison to 18% NaOH cooked for 2 h, the thickness of the paper sheet sample for 18% NaOH cooked for 1.5 h is thicker. The resulting control sample measured 245.28 µm in thickness. The thickness for the 2 h and 18% of NaOH. pulping condition sample was less (200.96 µm). 44.32 µm is used to illustrate the various dose thicknesses for alkaline pulping between 18% NaOH with 1.5 h of cooking time and 18% NaOH with 2 h. Based on previous research, Khair & Masrol [13], the result thickness obtained was 578.9 µm. The thickness parameters of the two scenarios differed significantly, according to an ANOVA study. The thickness of the paper sheet sample can be manipulated using different alkaline pulping conditions. The results of the ANOVA test show that the thickness difference between the two scenarios is not significant. This suggests that alkaline pulping can be used to make the paper sheet thicker or thinner depending on the desired outcome.

3.4 Surface Morphology of Paper sheet

With 200 X and 500 X magnification, Figure 10 displays SEM images of the surface morphology for a paper hand sheet made from D. Asper bamboo. D. Asper fibres are a long-fibered substance, as shown in the SEM image of the paper. It demonstrates that the fibre has an uneven surface and a slack internal structure. It is evident from the low tensile and tearing index, which is significantly impacted by the paper's fibre structure. The morphology displayed voids, pulled-out fibres, and broken fibres. Low burst strength results will be shown in the void area, and the paper will either strengthen or not. At the same time, no vacant area will have a high burst strength. There are no significantly different pores and fibres between both conditions.

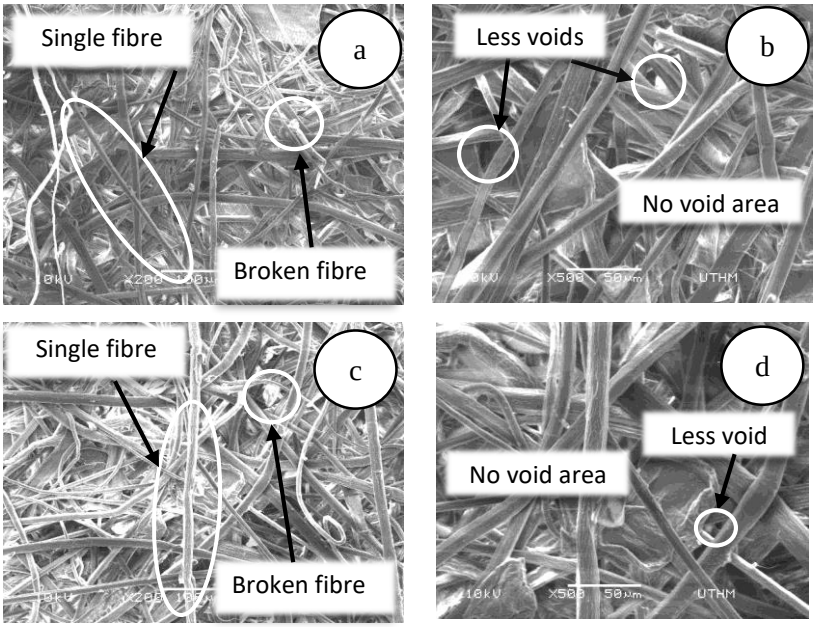

Figure 10: (a,b): Image of surface morphology 1.5 hours of cooking time with the magnification of 200 X and 500 X, (c,d) Image of surface morphology 2 h of cooking time with a magnification of 200 X and 500 X

4. Conclusion

In conclusion, the use of NaOH in paper strengthening allows the production of a sample of non-wood fibre paper goods. With the right cooking time, NaOH is required to increase mechanical paper characteristics and paper strength. The TAPPI standard and MS ISO standard can be used to determine the structural and mechanical characteristics of the paper product sample at the conclusion of sample preparation. Last but not least, information on the structural and strength qualities is used to determine the statistical analysis.

The findings of this study have demonstrated that the alkaline pulping process is an effective method for producing pulp from *D. Asper*. The alkali treatment has successfully removed lignin from the fibres and has resulted in a stronger and softer paper. The paper's mechanical and structural characteristics have also been positively impacted by the alkaline treatment. Furthermore, the study has shown that the cooking times for pulping shows no significant different in mechanical and structural properties. This is an important contribution to the pulp and papermaking industry, as it is beneficial for reducing costs associated with the process. ANOVA showed that no significant for all properties

(structural and mechanical). The lower parameter (18% NaOH, 1.5 h) chose because it almost got the same properties with the other parameter (18% NaOH, 2 h). By choosing the lower parameter and lower the cost of the experiment and less time to cook the D. Asper fiber.

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