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Characteristics of MD2 Pineapple Leaf Kraft Pulp and Paper Blended with Recycle Carton Box

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Abstract

The increasing environmental impact of traditional papermaking, primarily due to deforestation and high resource consumption, necessitates the exploration of sustainable alternatives. This study investigates the potential of MD2 pineapple leaf fiber as a non-wood-based raw material for papermaking, blended with a recycled carton box (RCB). The primary objectives are to produce liner paper from MD2 pineapple leaf kraft pulp blended with RCB and evaluate its physical and mechanical characteristics. Five blend proportions were tested in this study: 100% MD2, 75% MD2 and 25% RCB, 50% MD2 and 50% RCB, 25% MD2 and 75% RCB, and 100% RCB. The methodology involves preparing MD2 pineapple leaf pulp and RCB, followed by the soda-AQ pulping process. Laboratory papermaking procedures were employed to produce paper sheets, which were subjected to various physical and mechanical tests, including tensile strength, tear resistance, burst strength, and folding endurance, in accordance with TAPPI and MSISO standards. The results reveal an increasing trend in tensile strength, tearing resistance, and folding endurance as RCB content increases. Conversely, MD2 enhances burst strength across the blends, with the 25% MD2 and 75% RCB blend identified as the most optimal due to its balanced physical and mechanical properties. This research highlights MD2 pineapple leaf fiber as a viable alternative raw material, offering significant environmental benefits and contributing to sustainable papermaking practices.

1. Introduction

The increasing environmental impact of traditional papermaking, primarily due to deforestation and high resource consumption, necessitates the exploration of sustainable alternatives. Paper is a material that plays a crucial role in daily life, serving as a basic element in communication, education, and various industries. The procedure of producing paper is a complex and resource-demanding process, consisting of numerous steps that require a high level of resource consumption [1]. In recent years, the focus has shifted to finding sustainable practices and innovations in the paper industry to reduce the utilization of common wood sources and promote the effective use of agricultural residues. Pineapple leaves, a high cellulosic agricultural residue, have gained attention as a promising non-wood-based raw material for papermaking due to their favorable characteristics, such as high cellulose content, stiffness, and high aspect ratio [2]. In Malaysia, pineapple is a prominent crop, with over 17,601 hectares of pineapple plantations, making it an ideal candidate for such applications [3]. The production of paper has significant environmental consequences, including the cutting of approximately 312 trees, emission of 73,970 lbs of CO_2 gas, consumption of 144,742 kWh of energy, generation of 29,614 lbs of solid waste, and wastage of 247,975 gallons of water [4].

To address these challenges, the focus has shifted to eco-friendly and sustainable raw materials. Pineapple leaves, an abundant agricultural residue in Malaysia, offer a viable alternative due to their high cellulose content and suitability for papermaking. Malaysia is among the leading producers and exporters of pineapples, with significant potential for utilizing pineapple leaf fiber in the paper industry [5]. This research focuses on MD2 pineapple leaves, a high-value pineapple variety widely cultivated in Malaysia, and explores their potential as a sustainable raw material for papermaking, blended with recycled carton box (RCB).

2. Materials and Method

2.1 Soda-Anthraquinone (AQ) Pulping

In this process, a series of processes were initiated to cook the pineapple leaf. The oven-dry (o.d.) weight of the pineapple leaf was weighted then the dried leaves were inserted into the rotary digestor. It is put together evenly with chemicals and distilled water. A Soda-Anthraquinone (AQ) pulping process as illustrated in Table 1 was performed using 900 g o.d. dried MD2 pineapple leaves [6].

Table 1: Soda-Anthraquinone (AQ) pulping conditions of the MD2 pineapple leaf [6]

Soda-Anthraquinone (AQ) Pulping Condition	Value
NaOH concentration	20 %
Liquor to fiber ratio	8:1
Cooking Temperature	170 °C
Time to Reach Cooking Temperature	90 minutes
Time at Cooking Temperature	90 minutes
Anthraquinone (AQ)	0.1%

A comparable study conducted by Sibaly and Jeetah [7] using 15% NaOH with a cooking time of 90 minutes yielded pulp with a tensile index of 6.5 N·m/g and a burst index of 0.84 kPa·m^2/g. Therefore, this study utilized the same parameters with an increased chemical dosage of 20% NaOH to enhance screen yield and minimize screen rejects [7]. Meanwhile, the addition of anthraquinone in the pulping process accelerates delignification, reduces cooking time and temperature requirements, and enhances the overall pulp yield and strength [8]. A study by Mahatme shows soda pulping process was conducted at 80-90°C for 2 hours with a NaOH concentration of 12% with findings that an increase in tensile index [8].

2.2 Preparation of Laboratory Hand Sheet

A series of procedures were carried out to transform the pineapple leaf kraft pulp blended with recycled carton box (RCB) soda-AQ into 120 gsm paper sheets, following the Technical Association of Pulp and Paper Industry (TAPPI) T-205 standard, "Forming Hand sheet for Physical Test of Pulp." The blends consisted of five proportions: 100% MD2, 75% MD2 and 25% RCB, 50% MD2 and 50% RCB, 25% MD2 and 75% RCB, and 100% RCB. The pulp was disintegrated using a pulp disintegrator with 3000 revolutions (Figure 1a). The disintegrated pulp was then poured into the stock divider, and additional water was added to reach a total volume of 14 liters (Figure 1b). Two sets of freeness samples (1 liter each) were collected and tested in accordance with TAPPI T 227 om-99. After freeness testing, water was added back into the Stock Divider to restore the 14-liter volume. Two sets of correction samples (1 liter each) were then removed to verify whether the paper sheet weight matched the standard weight of 2.44 g. Once the correction test was completed, the remaining 12 liters of diluted pulp slurry were used to produce test samples using the hand sheet former. A bloating paper and a couching plate were placed over the formed sheet, which was then rolled five times with a roller. The formed hand sheet was carefully removed along with three pieces of bloating paper and the couching plate. To achieve a uniformly flat hand sheet, a pneumatic sheet press was used, applying a pressure of 345 kPa for 10 minutes during the first press and an additional 5 minutes for the second press (Figure 1d). The paper sheets were then placed on a polished steel plate and arranged alternately between drying rings to ensure a flat surface. The dry rings were then put in a temperature-controlled environment set at 23 ± 1°C and 50 ± 2% relative humidity, in compliance with TAPPI T 402 sp-03 standards, for a minimum of 24 hours (Figure 1e). Finally, the dried hand sheets were removed from the plates and drying rings and conditioned in a control room for an additional 24 hours before testing (Figure 1f).

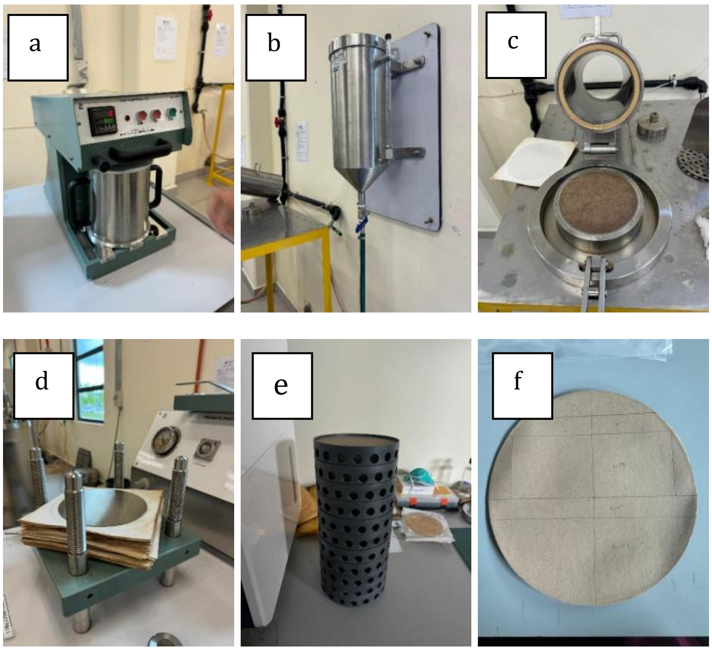

Fig. 1: (a) Pulp Disintegrator (b) Stock Divider (c) Hand sheet Former (d) Pneumatic Sheet Press (e) Drying Rings (f) Hand sheet sample

2.3 Pulp and Paper Properties Testing Procedure

Eight (8) samples of MD2 pineapple leaf paper blended with recycled carton box (RCB) were selected for characteristic testing. The test standards and equipment used for these tests are outlined in Table 2. The findings were documented and analyzed to calculate the mean and standard deviation of the data.

Table 2: Pulp and Paper Properties Testing Procedure

No.	Test	Standard	Machine/Device
1	Freeness	TAPPI T 227 om-99	Freeness Tester
2	Drainage Time	TAPPI 221	Hand sheet Former
3	Thickness	TAPPI T 411 om-97	Precision Micrometer
4	Density	MS ISO 534	-
5	Grammage	MS ISO 536	Drying Oven/ scale
6	Tensile	MS ISO 2470-1	Horizontal Tensile Testing Machine
7	Tearing Tester	MS ISO 1974	Tearing Tester
8	Bursting	MS ISO 2758	PTA-Line Burst Tester
9	Folding No	MS ISO 5626	Folding Endurance Tester

3. Results and Discussion

3.1 Pulp Characteristics

Key properties such as pulp moisture content, freeness, and drainage time are critical factors to be evaluated in the papermaking process. The pulp properties obtained from the pineapple leaf in this experiment are summarized in Table 3 and Table 4. The freeness test showed that freeness increased with higher RCB content, reaching a maximum of 855 ml at a 50% MD2 and 50% RCB blend, indicating improved drainage and fiber bonding. The drainage time decreased significantly with the addition of RCB, with 75% MD2 and 25% RCB achieving a drainage time of 5.12 seconds, demonstrating the positive effect of RCB on facilitating faster drainage.

Table 3: Moisture content

Pulp	Moisture content (%)
MD2	74.17
RCB	82.67

Table 4: Pulp freeness and drainage time

Pulp properties	100% MD2% [6]	75% MD2, 25% RCB	50% MD2, 50% RCB	25% MD2, 75% RCB	100% RCB [9]
Freeness (ml)	160	790	855	750	381.5
Drainage Time (s)	90.4	5.12	5.76	6.45	9.82

3.2 Physical Characteristics

To assess the quality of the produced paper, its physical properties, including grammage, thickness, and bulk density, were analyzed. As presented in Table 5, the physical properties of the MD2 pineapple leaf paper blended with a recycled carton box were calculated and documented in the experiment.

Table 5: Physical properties

Physical properties	100% MD2% [6]	75% MD2, 25% RCB	50% MD2, 50% RCB	25% MD2, 75% RCB	100% RCB [9]
Average Grammage (gm^{-2})	114.717	121.61	120.77	120.32	116.45
Average Paper Bulk Density (g/cm^3)	0.522	0.391	0.418	0.429	0.237

The grammage of the paper was measured in grams per square meter (g/m^2), commonly referred to as the gsm unit. A total of 16 paper samples, obtained from the tearing test, were conditioned for 24 hours using a drying oven. The grammage of the produced paper samples was recorded as 121.61 gsm, 120.77 gsm, and 120.32 gsm, which closely aligns with the target value of 120 gsm. The 75% MD2, 25% RCB blend has a density of 0.391 g/cm^3, and the 50% MD2, 50% RCB blend shows a density of 0.418 g/cm^3. The 25% MD2, 75% RCB blend has a slightly higher density at 0.429 g/cm^3. The result shows the average paper bulk density of the RCB was increased by the addition of MD2 pineapple leaf kraft pulp. These results suggest that increasing RCB reduces the paper's density, while MD2 contributes to a denser structure.

3.3 Mechanical Characteristics

Mechanical characteristics of paper are conditions that determine the response of the paper in the engineered process mechanical properties of the paper refer to behaviour when subjected to mechanical loads. This will then be used to measure the quality of the paper produced. Table 6 below shows the mechanical properties of the paper from each blend of MD2 and RCB pulp.

Table 6: Mechanical properties of MD2 Kraft pulp blends with RCB

Condition	100% MD2% [6]	75% MD2, 25% RCB	50% MD2, 50% RCB	25% MD2, 75% RCB	100% RCB [9]
Tensile Index (N.m/g)	40.92	11.83	16.61	19.32	20.48
Tearing Index ($mN.m^2/g$)	4.59	1.35	1.93	2.46	7.44
Burst Index ($kPa.m^2/g$)	2.73	2.30	2.03	2.11	1.37
Folding no (double fold)	13	3	4	5	9

The tensile test was conducted on the paper sample to calculate the paper's response to tensile and to estimate the proportional contribution of interfiber bonding and the individual fiber strength. The tensile index data also trends where the 100% MD2 paper has the highest tensile strength of 40.92 N.m/g thus suggesting that MD2 pulp offers better strength. It shows that when the proportion of RCB increases, the tensile index at first declines sharply in the 75% MD2, 25% RCB condition (11.83 N.m/g), and then slowly rises to 20.48 N.m/g in the 100% RCB condition. This means that although RCB reduced tensile strength of MD2 pulp, the strength of the paper is not progressively diminished after a certain level of RCB incorporation.

The tearing index data shows that as the proportion of RCB increases, the tearing resistance of the paper also improves. The 100% MD2 paper has a moderate tearing index of 4.59 $mN.m^2/g$, which decreases significantly in the 75% MD2, 25% RCB condition (1.35 $mN.m^2/g$). However, the tearing strength increases as RCB proportion rises and peaks at 100% RCB with a value of 7.44 $mN.m^2/g$, indicating RCB enhances tear resistance in the blended paper.

The burst index data shows a decreasing trend as the RCB content increases. The paper made from 100% MD2 has the highest burst strength (2.73 $kPa.m^2/g$), meanwhile, 100% RCB has the lowest burst strength (1.37 $kPa.m^2/g$). 75% MD2 blended with 25% RCB shows the highest value of 2.30 kPa.m2/g for blended pulp condition. It shows the burst strength decreases initially with higher RCB content but slightly rises again in the 25% MD2, 75% RCB blend. This suggests that MD2 pulp contributes significantly to burst strength and high RCB content reduces it.

The folding number declines as the content of RCB rises to its minimum of 3 folds in the 75% MD2, 25% RCB blend. But as the percentage of RCB increases, the folding endurance rises a little to 100% RCB which is 9 folds. This implies that the blending of MD2 pulp into RCB has reduced the folding resistance, although the increment of RCB dosage also has a positive effect on the folding resistance.

4. Conclusion

This study evaluated MD2 pineapple leaf fiber as a non-wood raw material for papermaking, blended with a recycled carton box (RCB), and analyzed the physical and mechanical characteristics of the resulting paper. The findings indicate that increasing RCB content improves tensile, tearing, and folding indices, while MD2 enhances burst strength, though slightly reduced in the 50% MD2 and 50% RCB blend. Drainage time significantly decreased in all blends, demonstrating improved efficiency. Based on the bulk density and mechanical characteristics, the 25% MD2 and 75% RCB blend emerged as the most optimal, balancing MD2's contribution to burst strength with RCB's enhancement of tensile, tear, and folding endurance. This also may be due to the interfiber bonding between shorter MD2 pineapple leaf fiber and longer RCB. This study confirms MD2 pineapple leaf fiber's viability as a sustainable raw material for eco-friendly papermaking with balanced properties.

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