DURIAN FRUIT SKIN PULP TO ENHANCE THE STRENGTH CHARACTERISTICS OF RECYCLED PULP DERIVED FROM PRINTED PAPER HEATED USING A LASER PRINTER

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ABSTRACT

Nyoman J. Wistara. Durian Fruit Skin Pulp To Enhance The Strength Characteristics of Bicycle Pulp Derived From Printed Paper Heated Using A Laser Printer.

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PKD was processed with soda at 20% AA, a liquor-to-wood ratio of 4:1, and 170°C for 4 hours without bleaching. SWL underwent heat treatment in the printer, was fed five times at 160°C, and was subsequently repulped. The mixture of PKD and SWL was prepared at weight/weight compositions of 100/0, 75/25, 50/50, 25/75, and 0/100, with three freeness levels: 300 CSF, 200 CSF, and 100 CSF. The dimensions and derivative values for KD predominantly fall into fiber quality class II, except for felting power, which is classified as class III. SWL is categorized in quality class III. The solubility levels of ethanol-benzene, holocellulose, lignin, and α-cellulose for KD are 23%, 65.39-67.28%, 16.34-18.17%, and 41.16-42.38%, respectively. In 1% NaOH, the solubility hierarchy is as follows: fiber KD > PKD 300 CSF > PKD 200 CSF > SWL. Notably, the mechanical properties of the sheet pulp mixture diminished as the composition of PKD increased, likely due to PKD's higher content of low-molecular-weight polysaccharides and elevated cellulose degradation. In contrast, the mechanical properties of SWL can be enhanced through beating.

Keywords: Beating, Mechanical properties, KD Pulp, SWL Pulp

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INTRODUCTION

The recycling and reuse of industrial waste materials have primarily stemmed from the need to improve environmental quality and enhance the efficiency of material and energy use (Bystrom and Lonnstedt 2000). The Environmental Protection Agency has documented gains in material utilization efficiency and environmental quality from recycled pulp production (Branco 2008, as cited in Sheiki et al. 2010). Specifically, modern advances in water-use efficiency and reductions in air emissions have enabled recycled pulp production to achieve 50% and 74% improvements, respectively, compared with virgin pulp production.

This shift toward recycling not only yields financial benefits but also delivers significant environmental advantages, thereby increasing demand for recycled pulp. Projections for 2015 indicate that demand for recycled paper will reach 460 million tons, reflecting an increase of 90 million tons since 2006 (Mocchiutti et al. 2011). Furthermore, the current share of recycled fiber in paper products has reached an impressive 70% (Chen et al. 2012).

Recycled paper tends to degrade in its mechanical and physical properties due to mechanical and chemical treatments that impair fiber development, flexibility, and fiber bonding (Sheikhi et al. 2010). The recycling process also shortens fiber length, a critical factor in determining the paper's physical strength (Cabalova 2011; Jahan et al. 2010). Several methods have been proposed to improve the quality of recycled paper, including grinding, chemical additives, fractionation, and blending, each with its own advantages and disadvantages (Wanrosli et al. 2005). Notably, many paper mills use mixed fibers, incorporating virgin fibers, to bolster the strength of recycled paper.

To enhance recycling capabilities, non-wood fibers have emerged as a viable alternative to conventional wood sources (Sheikhi et al. 2010). These materials are not only abundant but also have a shorter cultivation cycle than traditional wood (Belkhir et al. 2013). The integration of non-wood fibers has improved the flexibility of recycled fibers (Wanrosli et al. 2005), thereby addressing the inherent mechanical weaknesses associated with recycled paper compared with paper produced from virgin fibers (Mocchiutti et al. 2011).

In parallel, the durian fruit, recognized for its potent odor, distinctive spiky rind, and unique flavor, is an esteemed tropical fruit originating from Southeast Asia (Wai et al., 2010). Notably, the peel accounts for over 50% of the fruit's total biomass when compared to its seeds and edible pulp, underscoring the potential utility of durian peels. This significant proportion has spurred research and applications aimed at leveraging the value of this byproduct.

Extensive investigations have been conducted regarding the utilization of durian fruit peels for a range of purposes. These uses include serving as raw materials for the production of particle boards and fibers, creating bio-based adhesives (Wai et al., 2010), and acting as biological absorbents. In addition, durian peels have been explored as flavoring agents in food products (Foo and Hameed, 2011), demonstrating their versatility beyond mere disposal.

Despite notable advancements in the field, the use of holocellulose derived from durian fruit peels to improve the mechanical properties of recycled paper remains underexamined. This study aims to evaluate the mechanical properties of pulp derived from durian peel fibers, particularly after initial processing steps such as grinding and thorough mixing.

A comprehensive understanding of the mixed pulp's properties is critical, as it will illuminate the feasibility of employing durian peel fiber as a raw material within the pulp and paper industry. This research could facilitate not only a reduction in agricultural waste but also the sustainable integration of agricultural by-products into innovative manufacturing processes.

Durian fruit, a renowned tropical fruit from Southeast Asia, is characterized by its distinctive odor, morphology, and flavor (Wai et al. 2010). Notably, the mass of durian peel exceeds 50% of the total fruit weight when compared to seeds and pulp. Prior research has explored various applications of durian peels, including their use as raw materials for particleboard, fibers, adhesives (Wai et al. 2010), biological absorbents, and as flavoring agents in food products (Foo and Hameed 2011). However, the use of holocellulose extracted from durian peels to enhance the strength of recycled paper has not been adequately investigated.

This study, therefore, focuses on characterizing the mechanical properties of mixed pulp subjected to preliminary treatments involving grinding and mixing. The findings will be pivotal in assessing the potential of durian peel fiber as a viable raw material for pulp production.

MATERIALS AND METHODS

The rind of the fresh durian fruit is carefully sliced into flakes measuring approximately 4-5 cm in length and width, with a thickness of 5 mm, using a kitchen knife. These durian peel flakes are then sun-dried for two days. After drying, they undergo a soda cooking process, using a 20% AA solution for 4 hours, while maintaining a maximum temperature of 170°C and a liquor-to-weight ratio (L/W) of 4:1. The resulting pulp is filtered and thoroughly washed to remove any residual black leachate. The yield is then quantified based on the dry weight of the cooked flakes. Additionally, the Kappa number of the durian fruit peel pulp is assessed in accordance with TAPPI T 236 cm-85.

In this study, the paper used is A4-sized white office paper (white ledger) with a basis weight of 80 gsm. A preliminary treatment involves heating the paper at approximately 160°C through five cycles in a photocopier. Following this treatment, the paper is soaked in water for two days to facilitate fiber decomposition, which converts it into pulp.

The chemical composition analysis of the durian fruit peel includes parameters such as extractives, lignin, holocellulose, α-cellulose, and solubility in 1% NaOH. These parameters are determined using the Soxhlet extraction method with a solvent mixture of ethanol and benzene (1:2, v:v) and water for 8 hours, in accordance with TAPPI T 222 cm-98, ASTM D 1104, TAPPI T 203 cm-88, and TAPPI 212 om-88 standards.

The durian peel pulp is processed according to the TAPPI T 248 cm-853 standard procedure. Three distinct grinding levels are utilized: 300 CSF, 200 CSF, and 100 CSF. The durian fruit peel pulp is mixed with used paper pulp in the following compositions (on a weight basis): 100/0, 75/25, 50/50, 25/75, and 0/100. The resulting mixed pulp is then formed into sheets to test their strength properties. The properties tested include tensile strength, tear resistance, and cracking, using the standard procedures TAPPI T 404 om-87, TAPPI T 414 om-88, and TAPPI T 403 om-88, respectively.

This experiment employed a factorial ANOVA design at a 95% confidence level, along with Tukey's follow-up test, to assess the effects of varying ratios of durian fiber and waste paper, as well as the fineness of the pulp, on the mechanical strength of the mixed paper. The general model of the experimental design is as follows:

$$Yijk = U + ai + \delta ik + \beta j + \alpha\beta ij + \varepsilon ijk$$

Description :

i = 1.2,... a (Durian peel pulp concentration level)
j = 1,2,… b (Taraf freness level)
k = 1,2,3 (Deuteronomy)
Yij = Joint influence response of factor a and j factor b level in k observation
U = General Average Value
αi = Effect of the level i of the Holocellulose concentration factor
δik = Fierce Influence of the main compartment
βj = Effect of the jth level of the freness level factor
αβij = Effect of the interaction between the i-level of factor a and the j-level factor b
εijk = Error in the experimental unit from the ith level of factor a to the jth level of factor b of the k repetition

RESULTS AND DISCUSSION

Yield and Kappa Number

The screened yield of the pulp extracted from durian fruit peel is determined by comparing the dry weight of the produced pulp to the dry weight of the flakes derived from the durian peel. In this analysis, the pulp yield was 15.6%, and the kappa number was 34.22, indicating the pulp's lignin content. Prior to this measurement, a series of preliminary experiments was conducted at alkali concentrations of 16%, 18%, and 20%. The findings on the yield and kappa number of unbleached pulp from durian fruit peels are summarized in Table 2.1, which provides a detailed overview of how different processing conditions affect the pulp's quality and quantity.

Table 2.1 Yield and number of kappa *unbleached* pulp of durian fruit peel

AA (%)	Yield (%)	Kappa Number		Remarks
20	15.6	12.4	34.22*	Forest Products Chemistry Lab
16	10.6	17	-	Forest Products Chemistry Lab
18	13.6	15	-	Forest Products Chemistry Lab

* Kappa number results in the BPPK Bandung laboratory

Table 2.1 shows that the optimal yield was achieved at a 20% active alkaline (AA) concentration, which produced the highest extraction efficiency. In contrast, during the pre-study phase, AA concentrations of 16% and 18% yielded only 10.6% and 13.6%, respectively. This lower yield can be attributed to the high extractive content in durian fruit peels, which complicates the treatment process.

The results indicate that the solubility of ethanol-benzene-extracted durian fruit peels is approximately 23%. This relatively high extractive level suggests a significant presence of soluble compounds, which can interfere with the effectiveness of cooking chemicals used for material treatment. According to Fatriasari and Hermiati (2008), elevated concentrations of extractive substances hinder the penetration of cooking chemicals into the raw materials. This not only increases alkaline consumption but also prolongs the delignification process, preventing it from reaching its full potential.

As a result, the cooking process is less effective, and lignin in durian fruit peels is not optimally degraded. Consequently, AA treatments at 16% and 18% exhibit higher kappa numbers, indicating greater residual lignin—further confirming the challenges posed by the high extractive content during extraction.

Mechanical Properties of Pulp

The fiber dimensions and the levels of chemical components in durian fruit peel pulp raw materials affect the strength properties of pulp and paper sheets.The physical characteristics of durian fruit peel pulp, particularly its fiber dimension and the concentration of chemical components, significantly influence the strength properties of the resulting pulp and paper sheets. One effective method for enhancing the strength of these fibers involves a physical treatment process that merges new fibers with recycled and milled fibers, as highlighted by Wanrosli et al. (2005). This milling treatment is essential, as it aims to enhance the bond strength between fibers, ultimately increasing the overall strength of the produced pulp sheets, as noted by Banavath (2011).

In this study, the strength properties of the mixed pulp sheets were systematically evaluated. Key tests were performed to measure tensile strength, tear resistance, and cracking characteristics. These tests are vital for assessing how the grinding process and the integration of durian pulp with recycled pulp influence the mechanical integrity of the mixed sheets. The methodologies used in these assessments adhere to recognized standards, specifically TAPPI 200 om-89 for tensile strength testing and TAPPI 220 om-88 for evaluating tear properties. These standards provide essential procedures for assessing pulp quality and understanding its contribution to the strength of the final paper product. By conducting these tests, the study aims to provide comprehensive insights into how physical treatments and material combinations can optimize the performance of pulp sheets derived from durian fruit peel. In addition, one approach to improving fiber strength is to physically treat new fibers by combining them with recycled and milled fibers (Wanrosli et al., 2005). Milling treatment is carried out to increase bond strength between fibers and the strength of the pulp sheet (Banavath, 2011). In this study, the strength properties of the mixed pulp sheets tested include tensile strength, tear strength, and cracking properties. The tests were conducted to determine the effect of grinding and mixing durian pulp with recycled pulp on the strength properties of mixed-pulp sheets. Tensile, tear, and crack tests are used to assess the mechanical properties of the pulp, with TAPPI 200 om-89 and TAPPI 220 om-88 serving as procedures for determining pulp quality and its contribution to the final product's strength.

Tensile Strength

The average tensile strength properties of mixed pulp sheets from this study are presented in Figure 1. The freeness and composition of the durian fruit peel pulp, combined with recycled pulp, significantly influence the tensile index. According to the advanced Tukey test at a 95% confidence level, neither freeness nor pulp composition showed a significant improvement in the tensile strength of the pulp sheets. Specifically, the inclusion of durian fruit peel pulp in the mixed pulp reduced tensile strength. Additionally, varying freeness levels did not substantially enhance the tensile strength, except for the combination of 100 CSF freeness and 25% durian fruit peel pulp. Figure 1 illustrates that as the proportion of durian fruit peel pulp increases, the tensile strength of the mixed pulp sheets decreases.

The heating process that recycled fibers undergo is believed to cause hornification, which limits the fibers' ability to develop and absorb water. This reduced capacity negatively impacts flexibility, fibrillation, inter-fiber bonding, and ultimately, the strength of the paper (Sheikhi et al., 2010). In contrast, milling has a positive effect. It promotes fiber development and enhances bonding, which are crucial for the paper's strength properties, especially tensile strength (Wistara and Effendi, 2011). Milling also increases the surface area of the fibers, which plays an important role in improving inter-fiber bonding (Bhardwaj et al., 2007).

Furthermore, an analysis of the dimensions and characteristics of recycled pulp fibers suggests that milling significantly influences the strength properties of recycled paper, as shown in Table 2.2. Recycled pulp fibers possess thick cell walls, wide cell diameters, and short lengths. The robustness of these fibers results in inadequate bonding surfaces, which necessitates mechanical processing to thin the fiber walls (Ververis, 2004). Thinner fibers provide a larger bonding surface, enhancing tensile strength, tear resistance, and folding endurance (Aprianis & Rahmayanti, 2009). The evaluation of recycled pulp fiber characteristics reveals low ring ratios, weaving strength, muhlstep ratios, flexibility ratios, and stiffness coefficients. Based on these findings, the dimensions and characteristics of recycled pulp fibers fall within quality class III under the LPHH pulp manufacturing raw material standards. Thin fibers create a wider surface area for bonding, resulting in higher tensile strength, breaking resistance, and folding endurance (Aprianis & Rahmayanti, 2009).

Table 2.2 Dimensions and derivatives of recycled pulp fibers and durian fruit peels

Fiber dimensions and derivatives	LPHH Pulp Quality Classification*			Recycled Fiber	Durian Fruit Peel
	I (100)	II (75)	III (50)		
Fiber Length (mm)	>2	1.0 - 2.0	<1	0.941	1.89
Fiber Diameter (mm)				0.017	0.02998
Fiber Thickness (mm)				0.00873	0.00456
Lumen Diameter (mm)				0.00861	0.02087
Rungkel Ratio	< 0.25	0.25 - 0.5	0.5 - 1	2.027	0.44
Felting Power	> 90	70 - 90	40 - 70	54.24	63.04
Muhlstep Ratio (%)	< 30	30 - 60	60 - 80	75.33	51.54
Flexibility Ratio	> 0.8	0.6 - 0.8	0.4 - 0.6	0.497	0.7
Coef of Rigidity	< 0.1	0.1 - 0.15	0.15 - 0.2	0.503	0.15
Value	451 - 600	301 - 450	151 - 300	200	425

* LPHH (1976) in Apriyanis and Rahmayani (2009)

The chemical properties, dimensions, and derivatives of durian peel fibers are believed to play a crucial role in determining the tensile index of the mixed pulp produced from these fibers. Table 2.2 summarizes the specific dimensions and characteristics of durian fruit skin pulp fibers, illustrating several key metrics. This table highlights a broad range of fiber diameters, lumen diameters, and overall fiber lengths. Notably, the large lumen diameter reported by Sudomo et al. (2007) is advantageous in the pulp manufacturing process because it increases the flexibility ratio. This enhanced flexibility facilitates fiber refining, thereby improving production efficiency.

Recent findings indicate that fresh durian fibers exhibit superior fiber development and water absorption capabilities compared to those derived from previously used fibers, as noted by Wanrosli et al. (2005). Despite these advantages, the inherent chemical properties of durian peel fibers have not shown a corresponding improvement in the tensile strength of the mixed pulp.

In this study, the solubility level of the fibers in ethanol-benzene was quantified at 23%. The lignin content ranged from 16.34% to 18.17%, and this lignin component is suspected to interfere with the interactions between cellulose and hemicellulose, disrupting the formation of fiber bonds. This disruption is likely to reduce the overall strength of the resulting pulp sheets, as discussed by Fatriasari and Hermiati (2008).

On a positive note, the levels of holocellulose and cellulose α observed during this investigation were relatively high, ranging from 65.39% to 67.28% for holocellulose and from 41.16% to 42.38% for cellulose α. The hemicellulose content ranged from 24.23% to 24.9%. It is also significant to mention that the solubility rate of both durian peel powder and durian peel pulp in a 1% NaOH solution was found to be notably elevated. For more detailed insights into this solubility, refer to Table 2.3.

Table 2.3 Solubility in 1% NaOH

No	Sample Type	Yield (%)	Remarks
1	Durian Skin Powder	40.9	40-60 mess
2	Durian fruit peel pulp	21.1	300 ml CSF
3	Durian fruit peel pulp	19.6	200 mL CSF
4	Recycled Pulp	9.3	300 ml CSF

The solubility of pulp in a 1% sodium hydroxide (NaOH) solution is a critical metric for evaluating fiber quality. As outlined by TAPPI (1990), this solubility assessment is instrumental in estimating the concentrations of low-molecular-weight carbohydrates and lignin, as well as gauging the degree of chemical degradation of wood during the pulping process. A high holocellulose content, as indicated by studies by Fatriasari & Hermiati (2008) and Khalil et al. (2006), is generally associated with high-quality pulp and high yield. However, there is concern that the holocellulose content in durian fruit skin fiber harbors a substantial proportion of low-molecular-weight carbohydrates, suggesting considerable degradation. This is further corroborated by the findings in Table 2.3, which demonstrate that the solubility of durian fruit peel and pulp in 1% NaOH exceeds that of recycled pulp.

Tear Strength

Fiber derivatives, particularly felting power, play a significant role in determining the tear strength of pulp materials. Research by Ververis et al. (2004) shows a direct correlation between weaving power and tear strength; as weaving power increases, so does tear strength. This relationship is shown in Figure 2, which presents the average thickness of the torn specimens analyzed in this study.

In a detailed examination of factors affecting tear strength, both freeness and the composition of the pulp—specifically, the mixture of durian fruit peel pulp with recycled paper pulp—were evaluated for their impact on the tensile index. After applying Tukey's follow-up tests at α = 95%, the results indicated that neither freeness nor the composition of these pulps significantly improved the tear strength of the resulting pulp sheets. Notably, in mixed pulp sheets, incorporating durian fruit peel pulp decreased tear strength, suggesting that this composition may not be ideal for enhanced durability.

Moreover, the freeness of the mixed pulp sheets did not significantly increase their tear strength. This lack of enhancement underscores the complexity of optimizing pulp mixtures for strength and durability.

Specifically, the weaving power of the durian fruit peel pulp, categorized as quality class III, is a crucial factor that may negatively affect the tearing strength of the mixed pulp. According to Ververis et al. (2004), lower weaving power correlates with a diminished tendency for the pulp to resist tearing. The findings from this study indicate that the weaving power of durian peel fibers is 63. 04, placing them firmly within quality class III (as detailed in Table 2.2. 2). The relatively low weaving power signifies a limited capacity for effective bonding between fibers, which is essential for creating a robust pulp structure. Ververis (2004) supports this view, suggesting that inadequate contact surfaces between fibers can hinder their structural integrity. Additionally, research by Fitriasari & Hermiati (2008) indicates that such reduced bonding capabilities can further diminish the fibers' flexibility, leading to lower overall tear strength in the final product. Thus, it can be inferred that the inherent characteristics of durian peel fibers may result in compromised tearing strength when used in mixed pulp compositions.

The analysis of the dimensions and derivatives of recycled pulp fibers, as shown in Table 2.2, classifies these fibers as quality III. Notably, when recycled pulp is ground to a CSF (Canadian Standard Freeness) of 300, its quality improves significantly. This improvement is evidenced by a tear strength that surpasses that of durian peel pulp. One possible explanation for the superior tear strength observed in recycled pulp is its relatively low NaOH solubility, which is measured at 9.3%. This characteristic indicates that recycled pulp undergoes less cellulose degradation than durian pulp, as detailed in Table 2.3.

However, the dynamics of tear strength are influenced by the extent of grinding. Specifically, grinding to a fineness of 100 CSF results in a significant decrease in tear strength. This reduction can be attributed to fiber shortening, as supported by research by Chen et al. (2012). Their findings suggest that excessive grinding can have detrimental effects, including reduced fiber length, which negatively impacts the material's mechanical strength. Consequently, this reduced fiber length is believed to be the reason why sheets made from durian peel pulp at 100 CSF fail to retain their form and structural integrity.

Bursting Strength

Cracking strength is a well-established parameter for assessing the mechanical properties of materials, particularly in paper technology, because it is straightforward to measure and independent of the paper's directional characteristics (Hidayat, 2009). As illustrated in Figure 3, this study presents the average crack properties of various pulp compositions. Freeness and the blend ratio of durian fruit peel pulp with recycled pulp significantly influence the crack index. However, Tukey's follow-up tests ($\alpha = 0.05$) indicate that neither freeness nor pulp composition yielded statistically significant improvements in the cracking strength of the sheets. Specifically, integrating durian fruit peel pulp into mixed pulp sheets has a detrimental effect on cracking strength, while adjustments in freeness show no notable enhancement, except at a freeness level of 100 CSF when mixed with 50% and 25% durian fruit peel compositions.

The factors influencing cracking strength align closely with those affecting tensile strength (Yuhana, 2012), namely the bonding strength between fibers (Purnamasari, 2012) and fiber length (Ververis, 2004). The analysis of the derivative properties of durian fruit peel pulp fibers (Table 2.2. 2) reveals that these fibers are categorized as quality class II based on their stiffness coefficient (KK) and flexibility ratio (FR). This classification suggests that the fibers exhibit rigidity and lack flexibility. Dutt et al. (2012) noted that enhanced fiber flexibility contributes positively to cracking strength, whereas a high stiffness coefficient tends to render fibers rigid (Fitriasari & Hermiati, 2008).

In contrast, the properties and dimensions of recycled pulp fibers (Table 2.2. 2) classify them as quality III fibers. Ververis (2004) pointed out that a low flexibility ratio can adversely affect pulp strength. However, grinding recycled pulp to a freeness of 300 CSF significantly improves its quality, resulting in a cracking strength that surpasses that of durian fruit peel pulp (Figure 3).

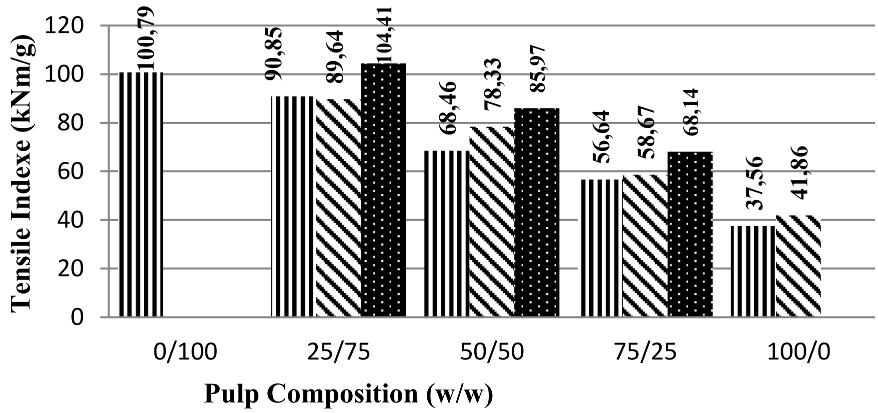

Figure 1 Tensile index diagram on multiple compositions and freeness of 300 ml CSF ( ), 200 ml CSF( ), and 100 ml CSF( )

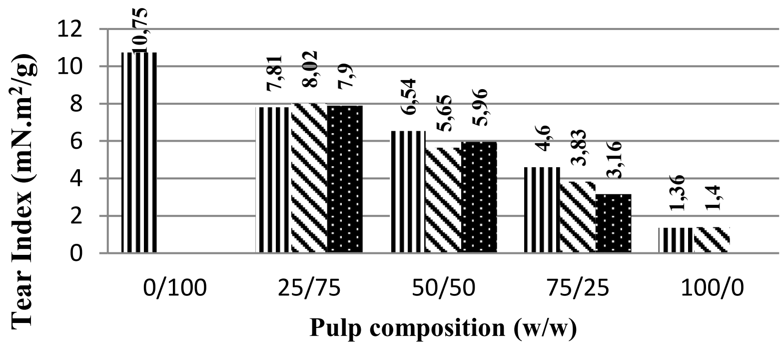

Figure 2 Diagram Index of tears in some compositions and freeness 300 ml CSF ( ), 200 ml CSF ( ), dan 100 ml CSF ( )

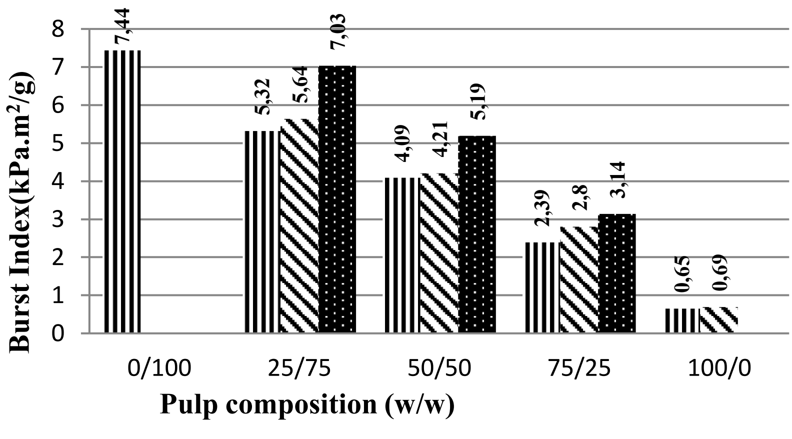

Figure 3 Diagram Burst index in some compositions and freeness 300 ml CSF ( ), 200 ml CSF ( ), dan 100 ml CSF ( )

CONCLUSION

Research findings indicate that neither freeness nor compositional adjustments have significantly improved the mechanical properties of mixed pulp. Specifically, the tensile strength, tear resistance, and crack resistance of mixed pulp sheets decline as the proportion of durian fruit peel pulp increases. While grinding has shown promise in improving the quality of recycled pulp, durian fruit peel fibers have been deemed unsuitable as a primary pulp raw material due to their low-molecular-weight polysaccharides and pronounced cellulose degradation. To address these challenges, treatments that reduce NaOH solubility by 1% are recommended to enhance the viability of durian peel fibers as pulp materials. Additionally, further investigations are warranted to explore the effects of varying compositions of durian husk pulp when combined with SWL pulp, as well as studies incorporating different cooking methods and preliminary treatments to optimize pulp characteristics.

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