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The Influence of Tensile Strength Test Values on the Elongation of Eco-Friendly Paper

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ABSTRACT
Paper is a thin material in the form of sheets. Environmentally friendly paper is obtained from natural materials derived from discarded waste. This study aims to investigate the characteristics and the effect of elongation values on the tensile strength of the produced paper. The composition variations between taro peel and oil palm frond fibers in paper production were 30%:70% (sample A); 40%:60% (sample B); 50%:50% (sample C); 60%:40% (sample D); and 70%:30% (sample E). The pulp preparation process was carried out using the soda method, while the drying process was conducted naturally at room temperature for 12 hours. The results of the paper characterization for samples A, B, C, D, and E showed tensile strength values of 5.2570 kN/m, 6.2875 kN/m, 7.1985 kN/m, 8.8975 kN/m, and 9.5060 kN/m, respectively, while the elongation test values were 1.09%, 1.12%, 1.15%, 1.24%, and 1.52%. These values have met the requirements for printing paper grade A according to SNI 7274:2008. The results indicate that the higher the composition of oil palm frond fibers used, the greater the tensile strength and elongation values of the paper.

Keywords: Elongation, Oil palm frond fibers, Paper, Taro peel, Tensile strength

ABSTRAK
Kertas merupakan bahan tipis dengan bentuk lembaran-lembaran tipis. Kertas ramah lingkungan diperoleh dari bahan alami yang berasal dari limbah yang terbuang. Penelitian ini bertujuan untuk mengetahui karakteristik dan pengaruh nilai uji daya regang terhadap ketahanan tarik pada kertas yang dihasilkan. Variasi komposisi antara kulit keladi dan serat pelepah sawit pada pembuatan kertas yaitu 30%:70% (sampel A); 40%:60% (sampel B); 50%:50% (sampel C); 60%:40% (sampel D) dan 70%:30% (sampel E). Proses pembuatan pulp menggunakan metode soda dan proses pengeringan kertas secara alami di suhu ruang selama 12 jam. Hasil karakteristik kertas yang dihasilkan pada sampel A, B, C, D dan E masing-masing untuk nilai uji ketahanan tarik adalah 5,2570 kN/m, 6,2875 kN/m, 7,1985 kN/m, 8,8975 kN/m dan 9,5060 kN/m, sedangkan nilai uji daya regang adalah 1,09% , 1,12%, 1,15%, 1,24% dan 1,52% yang telah memenuhi nilai persyaratan kertas cetak A menurut SNI 7274:2008. Semakin bertambahnya komposisi serat pelepah sawit yang digunakan maka akan semakin meningkat nilai ketahanan tarik dan daya regang pada kertas.

Kata kunci: Daya regang, Kertas, Ketahanan tarik, Kulit keladi, Serat pelepah sawit

1. Introduction

The effort to innovate in creating new environmentally friendly materials can be achieved by utilizing discarded natural raw materials such as taro peel waste and oil palm fronds, which can serve as an alternative to wood-based paper. Paper is a thin and flat sheet material. Its use in daily life is closely related to activities such as writing, wrapping, merchandise, and research materials such as filter paper, litmus paper, and others.

Traditionally, paper production relies on cellulose fibers from trees, leading to an increasing rate of deforestation each year, which in turn causes environmental damage [1]. The impacts of deforestation include barren forests that may trigger natural disasters such as landslides, as well as the addition of other harmful chemicals that, when decomposed, can damage the surrounding environment. A solution to this problem is to develop alternative raw materials to replace wood, thereby minimizing deforestation. In paper production, it is crucial that the raw materials used contain more than 40% cellulose [2]. Among potential alternatives are taro peel and oil palm frond fibers, both of which contain cellulose levels above 40% [3].

Taro peel contains various chemical compounds, including starch, proteins, fats, ash, fibers, and metallic minerals. The starch present in taro peel can act as a natural additive in the papermaking process, enhancing the bonding strength between cellulose fibers and thus producing stronger and higher-quality paper. In addition to reinforcing the paper's structure, taro peel starch also has the potential to replace synthetic chemicals in the paper industry, supporting a more eco-friendly and sustainable paper production process [4]. Besides taro peel, another waste material that can be utilized in papermaking is oil palm fronds, which are rich in cellulose. Oil palm fronds contain 40.96% cellulose [5]. Their high cellulose content and long fibers demonstrate significant potential for being processed into products with higher economic value.

Nugroho et al. (2022) conducted a study on paper production using taro peel as the raw material for pulp through the soda pulping process, aiming to determine the lignin content and the optimum pulp yield obtained from taro peel pulp production using the soda process, which was preceded by a pectin removal step [6]. Aisyah and Trihernawati (2023) investigated the utilization of oil palm fronds as an alternative raw material for paper production and reported that the resulting paper quality met the Indonesian National Standard (SNI) [7]. Furthermore, K.S. and Jumiati (2023) examined papermaking using durian peel and pineapple leaves with the soda process, producing grade A printing paper according to SNI 7274:2008 [8]. Similarly, Ningsih et al. (2023) investigated papermaking from pineapple leaves and cassava peel using the soda pulping method, which resulted in grade C paper according to SNI-14-0937-2005 [9].

Based on these conditions, further research is required to determine the effect of tensile strength on the elongation properties of environmentally friendly paper. The objective of this study is to evaluate the paper quality based on the tensile strength and elongation values obtained. The characterization conducted includes tensile strength and elongation tests in accordance with the quality requirements for A-grade printing paper as specified in SNI 7274:2008. The materials used in this study include taro peel, oil palm fronds, acetic acid, 1.5% NaOH, 10% H_2O_2, 2% Na_2SO_3, polyvinylpyrrolidone (PVP), and distilled water. This research employs a chemical method using the soda pulping process, which is expected to be applicable to paper products such as cardboard, envelope paper, and book paper [10].

2. Method

2.1. Tools and Materials

The tools used in this research included plastic container, vessel, erlenmeyer flask, beaker glass, glass funnel, dropper pipette, stopwatch, thermometer, porcelain crucible, watch glass, digital balance, 100-mesh sieve, Whatman No. 42 filter paper, oven, molding device, micrometer screw gauge, ball mill, hotplate magnetic stirrer, magnetic stirrer bar, and Universal Testing Machine (UTM).

The materials used in this research were taro peel, oil palm frond fibers, acetic acid, 1.5% NaOH, 10% H_2O_2, 2% Na_2SO_3, polyvinylpyrrolidone (PVP), and distilled water.

2.2. Research procedures

The preparation of raw materials for papermaking begins with the production of taro peel pulp and oil palm frond pulp using the soda process. The raw materials are refined using a ball mill and sieved with a 100-mesh sieve. The ground and sieved raw materials are then stored in a closed container. Next, pulp preparation is carried out by cooking with 500 mL of acetic acid at 100 °C for 90 minutes. The residue is filtered and washed with distilled water, resulting in the first filtrate residue. The first filtrate residue is then cooked using 750 mL of 1.5% NaOH solution and 150 mL of Na_2SO_3 at 50 °C for 60 minutes. The residue is filtered and washed with distilled water, producing the second filtrate residue. The second filtrate residue is then cooked again using 250 mL of 10% H_2O_2 at 70 °C for 30 minutes. The residue is filtered and washed with distilled water, resulting in the third filtrate. The third filtrate residue is further cooked using 500 mL of 1.5% NaOH at 80 °C for 30 minutes. The residue is filtered and washed with distilled water, producing the fourth filtrate residue. The fourth filtrate residue is then cooked using 500 mL of 10% H_2O_2 at 60 °C for 15 minutes. The residue is filtered and washed with distilled water, resulting in the fifth filtrate residue. The fifth filtrate residue is then dried in an oven at 105 °C for 60 minutes. The final product obtained is dried pulp from taro peel and oil palm fronds to be used as raw materials for papermaking [9].

The next stage is the preparation and testing of the paper. Taro peel pulp and oil palm frond pulp were weighed with compositional variations in Sample A (30%:70%), Sample B (40%:60%), Sample C (50%:50%), Sample D (60%:40%), and Sample E (70%:30%). The weighed pulp was then placed into a container and mixed with 50 mL of water, followed by stirring until homogeneous using a magnetic stirrer. After the pulp was evenly mixed, PVP (1% of the total weight of the material) was added. The mixture is then poured into a vessel containing 2 liters of clean water. The papermaking process is carried out using a paper mold, producing paper sheets. The sheets are dried at room temperature for 12 hours. The samples are then tested through characterization, including tensile strength and elongation tests, according to the quality requirements for grade A printing paper as specified in SNI 7274:2008.

2.3. Characterization

The results of the tensile strength and elongation tests comply with SNI 7274:2008. To determine the tensile strength of the paper that has been produced, testing must be carried out based on the SNI 14-0437-1998 standard. The procedure for measuring tensile strength is to clamp the ends of the sample with a specific width of 15–25 mm for tensile testing, then mount the sample on the tensile testing machine, apply tensile force until the sample breaks, and record the maximum force achieved. The tensile strength of paper is the resistance of a sheet of paper or cardboard to tensile forces applied at both ends of the paper or cardboard, measured under standard conditions. The measurement is carried out using a Universal Testing Machine (UTM). Tensile strength is defined as the maximum force divided by the surface area (in kilonewtons per meter). The tensile strength test can be calculated using Equation (1):

$$KT = F/A \tag{1}$$

where, KT is tensile strength (kN/m), F is maximum force (kN), and A is surface area (m).

Elongation is a mechanical property of the material used to determine the extent to which the material can stretch when subjected to stress. The greater the tensile strength of a material, the stronger the material is. It is measured using a Tensile Strength Tester. Elongation is the increase in length divided by the initial length. To determine the elongation of the paper that has been produced, testing must be carried out based on the SNI 14-0932-1998 standard. The procedure for measuring elongation is that during the tensile strength test, the increase in sample length is measured until the breaking point, and then the elongation is calculated using Equation (2):

$$\varepsilon = \Delta L / L_0 \times 100\% \tag{2}$$

where, ε is elongation (%), ΔL is increase in length (mm), and L_0 is initial length (mm).

3. Result and Discussion

3.1. Tensile Strength Test

The tensile strength data of the paper samples can be seen in Table 1.

Table 1. Tensile strength test data.

Sample	Tensile Strength Value (kN/m)	SNI 7274:2008 (kN/m)
A	5.2570	
B	6.2875	
C	7.1985	Minimum 2.0
D	8.8975	
E	9.5060	

Table 1 presents the tensile strength test values (in kN/m) for five groups of samples (A, B, C, D, and E). The tensile strength values range from 5.2570 kN/m (A, the lowest) to 9.5060 kN/m (E, the highest). The average tensile strength for each sample increases as follows: A (5.2570 kN/m), B (6.2875 kN/m), C (7.1985 kN/m), D (8.8975 kN/m), and E (9.5060 kN/m), which meets the requirements for printing paper type A according to SNI 7274:2008.

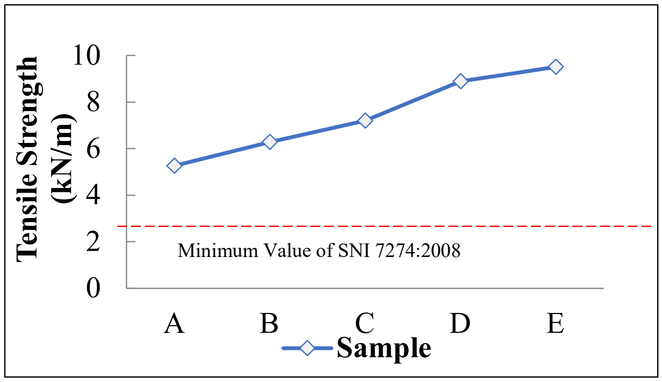

Figure 1. Graph of tensile strength test results.

Figure 1 shows that the tensile strength values increase along with the higher composition of oil palm frond pulp. When the amount of taro peel pulp with short and fine fibers decreases, while the oil palm frond fibers with longer and stiffer characteristics become more dominant, the paper can withstand greater tensile force before breaking [11]. The relationship between paper quality and tensile strength is determined by the number of inter-fiber bonds and the distribution of fibers in the sheet [12], [13]. In addition to having a high cellulose content that contributes to tensile strength, oil palm frond fibers can distribute tensile force more widely, making the paper sheets more resistant to tearing and thus increasing tensile strength [14].

The mixing and sheet-forming processes of paper samples also affect the strength/quality of the paper. The more homogeneous the pulp mixture, the stronger the inter-fiber bonds, which consequently increases the tensile strength of the paper [15].

3.2. Elongation Test

The elongation data of the paper samples can be seen in Table 2.

Table 2. Elongation test data.

Sample	Elongation Value (%)	SNI 7274:2008 (%)
A	1.09	
B	1.12	
C	1.15	Maximum 4.0
D	1.24	
E	1.52	

Table 2 presents the elongation test values (in %) for five groups of samples (A, B, C, D, and E). The elongation values range from 1.09% (A, the lowest) to 1.52% (E, the highest). The average elongation for each sample increases as follows: A (1.09%), B (1.12%), C (1.15%), D (1.24%), and E (1.52%), which meets the requirements for printing paper type A according to SNI 7274:2008.

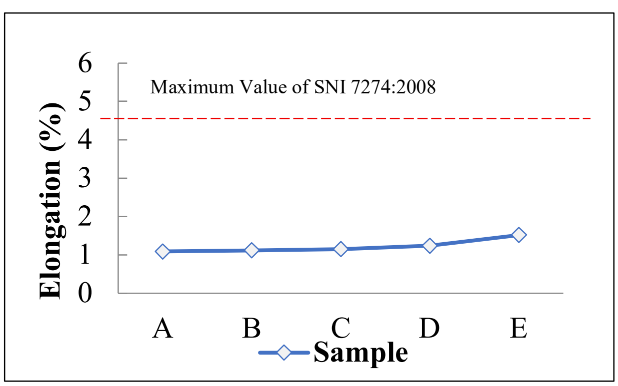

Figure 2. Graph of elongation test results.

Figure 2 shows that the elongation values increase as the proportion of oil palm frond fibers used increases, making the elastic and ductile properties in the paper sheets more dominant. This condition prevents the paper from breaking easily when pulled, thus increasing the elongation value [16]. Long fibers interlock more effectively within the paper structure, and the strong inter-fiber bonding combined with the elastic properties of the fibers contributes to higher resistance against elongation [17], [13].

3.3. Universal Testing Machine (UTM) Test

The UTM test results can be seen in Figure 3.

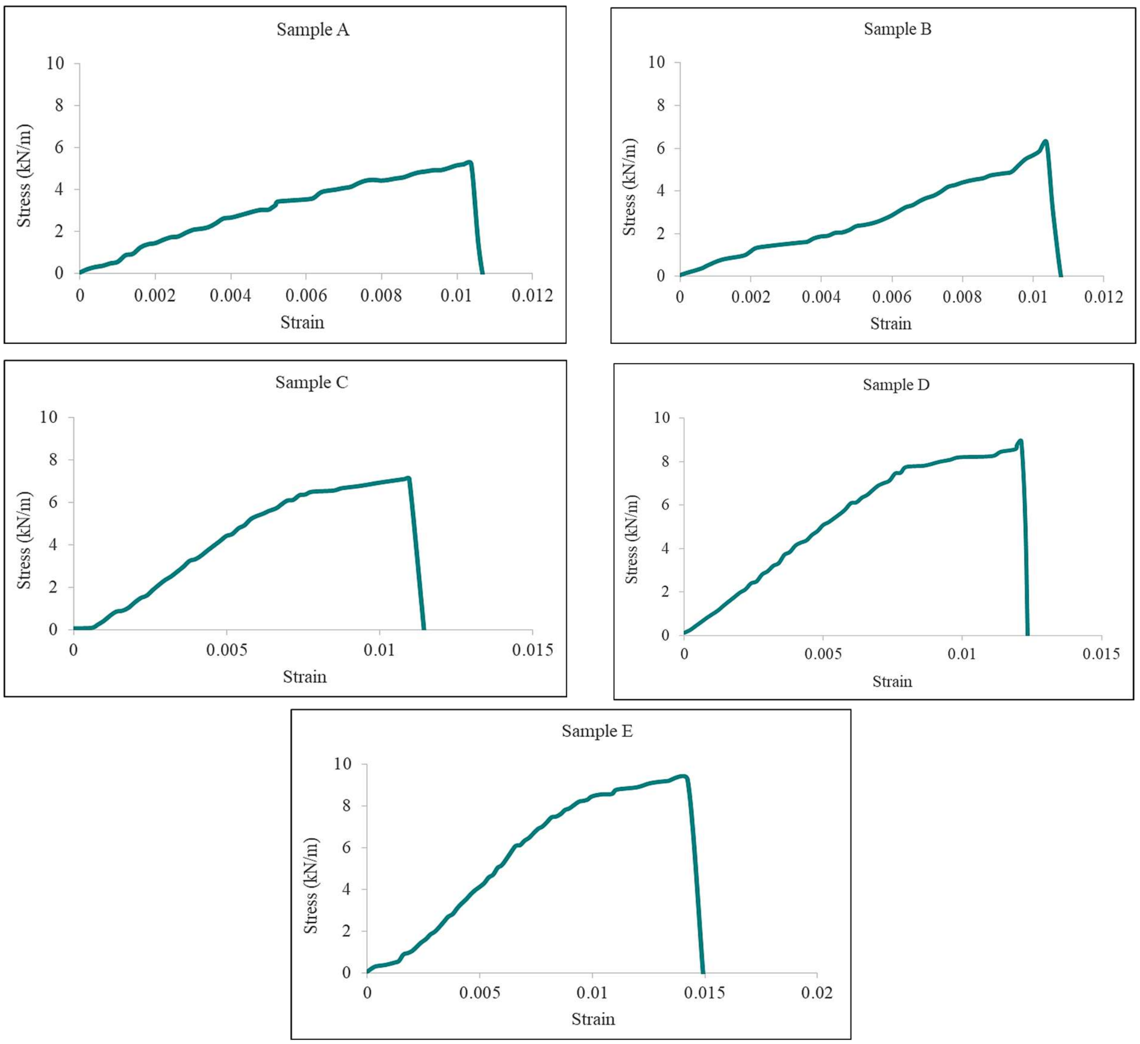

Figure 3. Graph of UTM test results.

4. Conclusion

The characteristics of eco-friendly paper made from taro peel and oil palm fronds show tensile strength values ranging from 5.257 to 9.5060 kN/m and elongation values ranging from 1.09 to 1.52%. The best quality among the composition variations in the production of eco-friendly paper was obtained in sample E, with a tensile strength value of 5.257 kN/m and an elongation value of 1.09%, which have met the requirements of grade A printing paper according to SNI 7274:2008 and can be applied for products such as carton paper, envelope paper, and book paper. The advantages of paper made from taro peel and oil palm fronds include their use as renewable and environmentally friendly raw materials, as they reduce dependence on wood fibers and help minimize waste disposal. These materials also offer potential for reducing deforestation. In addition, the fiber characteristics are promising, as fibers derived from oil palm fronds and taro peel can provide good mechanical strength when properly processed, while also creating added economic value for farmers and local industries.

Future challenges include variations in raw material quality due to differences in lignin, hemicellulose, and pectin contents of oil palm fronds and taro peel, which necessitate consistent processing standards. Additional challenges involve pulping efficiency, proper management of processing waste to prevent environmental pollution, and improving the physical and mechanical properties of alternative fiber-based paper to achieve tensile strength, ink absorbency, brightness, and smoothness comparable to conventional wood-based paper. Furthermore, industrial scalability requires evaluation of raw material supply logistics, production costs, and manufacturing technologies to ensure commercial feasibility and competitiveness.

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