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Enhancing the Mechanical Properties of Paper Products Using Nanofibrillated Cellulose (NFC) from *Gigantochloa scortechinii* (Buluh Semantan) as a Reinforcing Agent

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Abstract

This experiment investigates the reinforcing capability of nanofibrillated cellulose (NFC) derived from *Gigantochloa scortechinii* (Buluh Semantan) for paper production, with a focus on mechanical properties (tensile and tear) and physical properties (porosity). Paper made from Buluh Semantan pulp is incorporated with NFC extracted from the same species. In this study, Refiner Mechanical Pulp (RMP) and Chemical Mechanical Pulp (CMP) are used for comparison purposes. The incorporation of 5% and 15% NFC by weight improves the tensile index properties of RMP paper by up to 12% and 40%, respectively, while for CMP, the properties increase by as much as 200%. Regarding the tearing index, NFC enhances it by 14% for RMP paper, while for CMP, the tearing index exhibits some fluctuations. However, the presence of NFC significantly decreases porosity. This study reveals the reinforcing ability of NFC from Buluh Semantan in enhancing the tensile index of paper products and reducing porosity.

Keywords: Nanofibrillated cellulose, RMP, CMP, Reinforcing agent

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1. Introduction

The increasing global human population demands significant increases in plant-derived bioenergy and associated high-value products in global markets [1]. One of the major energy consumers is the global pulp and paper industry, which contributes to climate change, resource depletion, and other global environmental issues [2]. Therefore, the search for alternative raw materials to wood has intensified. A suitable raw material should be inexpensive, fast-growing, easily available, and possess physical and mechanical properties comparable to wood. Bamboo could serve as a viable alternative [3]. Furthermore, cellulose, the most abundant component of biomass resources, offers the potential for high-value applications. Nanocellulose, a cellulosic material with dimensions in the nanometer range, has garnered the attention of many researchers [4]. Its incorporation into bio-composite products, such as paper, has been shown to enhance strength and surface qualities [5].

Additionally, adding nanocellulose to polymer films, such as polyvinyl acid (PVA) and styrene-butadiene latex, has been claimed to improve modulus of elasticity, though not tensile strength in some cases [6]. However, certain studies have demonstrated that adding nanocellulose to PVA composites can enhance tensile strength and thermal properties [7]. In this study, NFC was produced from Buluh Semantan and used as reinforcement agent to improve the mechanical properties of paper from Buluh Semantan pulp.

2. Materials and methods

Buluh Semantan was harvested in the Hulu Langat district, and Chemiz supplied Sodium Hydroxide Pellets - AR (NaOH) for bleaching. Buluh culm was chipped and screened into various sizes, with a piece between 2 and 2.5 cm wide and 3 to 8 mm thick being selected for chemical pulping. Soda pulping was performed in a 16L rotary digester at 170°C for 3.5 hours (1.5 hours heating time) with a wood-to-liquor ratio of 1:6.

The pulp was then bleached using a 5-stage elemental chlorine free (ECF) DEDED process with 3% Sodium chlorite (NaClO2) for the D stages and 2% NaOH for the E stages. All bleaching phases were performed at 70°C for 120 minutes for stage 1, 60 minutes for stages 2 and 4, and 90 minutes for stages 3 and 5. For the extraction of nanocellulose, bleached cellulose was beaten using a PFI Mill for 20k revolutions before being treated with a Super Mass Colloider machine to obtain nano size cellulose. Atomic Force Microscope (AFM) was used to assess the size of the cellulose fiber to validate the formation of nanocellulose. In the preparation of laboratory hand sheets, two types of pulp were used: Refiner Mechanical Pulp (RMP) and Chemical Mechanical Pulp (CMP).

RMP pulp is widely employed in the lower-priced segment of printing paper production due to its cost-effectiveness. It also demonstrates excellent brightness and opacity [8]. The production process involves full mechanical grinding, with fibers refined using a single rotating grinding disc [9]. While the total yield ranges from approximately 90% to 98%, the resulting paper tends to have lower strength due to the presence of lignin that persists between the fibers.

They are interfering with hydrogen bonding during papermaking. Furthermore, this lignin content can lead to paper yellowing when exposed to air and light [10]. Semi-chemical pulping, on the other hand, is a two-stage process that combines both chemical and mechanical methods. In the initial stage, wood chips undergo chemical treatment to partially soften them, thereby reducing inter-fiber bonding through the removal of hemicellulose and lignin components. The subsequent stage involves mechanical refining, where the chemically treated biomass is processed into individual fibers and fiber bundles [11].

This semi-chemical pulping process provides versatility in pulp quality, with its suitability for various applications depending on the yield achieved. For instance, achieving a 75% yield results in excellent stiffness, making it particularly well-suited for the production of corrugated containerboard [12]. RMP and CMP were fabricated with the addition of 5 wt% and 15 wt% of NFC. The paper was then tested with Tensile, Tear and Porosity test to compare the incorporation effect of NFC to paper production. Individual tests were carried out according to methods listed in **Table 1.**

3. Results and Discussions

The effect of NFC incorporation was significant on tensile properties and porosity, however, there is no significant effect on tearing strength. **Figure 1** shows a tensile index of RMP and CMP pulp with the presence of NFC. CMP pulp exhibits a higher tensile index compared to RMP pulp. Individual fiber strength and physical contact with hydrogen bonding between hydroxyl groups on the fiber surface area affect the tensile strength [16]. The fiber length of CMP is longer than RMP due to the mechanical process that may cause the fiber to shorten [17]. This phenomenon contributes to good tensile strength for CMP compared to RMP. The pulp exhibits an increase in tensile strength after going beating process at 8,000 revolutions. During the beating process, breaking of inflated fibers exposes most of the individual fiber surface and increase the formation of hydrogen bonding and the stability of the paper is enhanced due to fiber connections where the beating pulp exhibit higher tensile strength than unbeaten pulp [18]. The presence of NFC also increases the tensile strength. The surface of nanocellulose is densely packed with free hydroxyl groups. When incorporated with pulp, it is spread in the gaps between the fibers or on the fiber surface. Then intimately mixed with the pulp fibers, strengthening the adhesion between the fibers filling the voids in the paper, and enhancing the paper's strength [19-22]. In the tensile test, CMP pulp with the addition of 15 wt.% of NFC exhibits the best tensile index properties (47.66 Nm/g), showing a 200% increase. For RMP, the addition of 5% and 15% of NFC results in a 12% and 40% increase in tensile index, respectively. **Figure 2** shows Tearing Index of RMP and CMP pulp with addition of NFC. Both RMP and CMP exhibit fluctuating value of tearing index. Tear strength is influenced by a variety of parameters, including the mean fiber length, the amount of hydrogen bonding, and the intrinsic strength of the fiber. The strengthening of lignocellulose nano-fibers increases the amount of hydrogen bonding and reduces the mean fiber length, resulting in fluctuating tearing strength properties [23]. The best tearing index exhibit by CMP pulp with beating at 8,000 revolutions (17.08 $mN.m^2/g$) without the presence of NFC. Porosity is an important property for paper strength, visual quality, optical characteristics, and applications, particularly in paper packaging [24]. In **figure 3**, RMP and CMP pulp exhibit decrease in porosity as diameter fibre decrease and presence of NFC. In **Figure 3**, both RMP and CMP pulp exhibit a decrease in porosity as fiber diameter decreases, especially in the presence of NFC. The specific surface area of cellulosic fibers increases as fiber diameter decreases, making hydroxyl groups more accessible on the fiber surface. These groups can then form hydrogen bonds with adjacent fibers, resulting in the formation of a fiber network and an improvement in paper strength and resistance to air permeability [25].

Table 1: Test method for preparation and testing sample.

Properties	Method
Hand sheet preparation	TAPPI T205 sp-02 [13]
Tensile Strength	MS ISO 1924-2: 2010 [14]
Tear Strength	MS ISO 1974: 1999 [15]
Porosity	In house

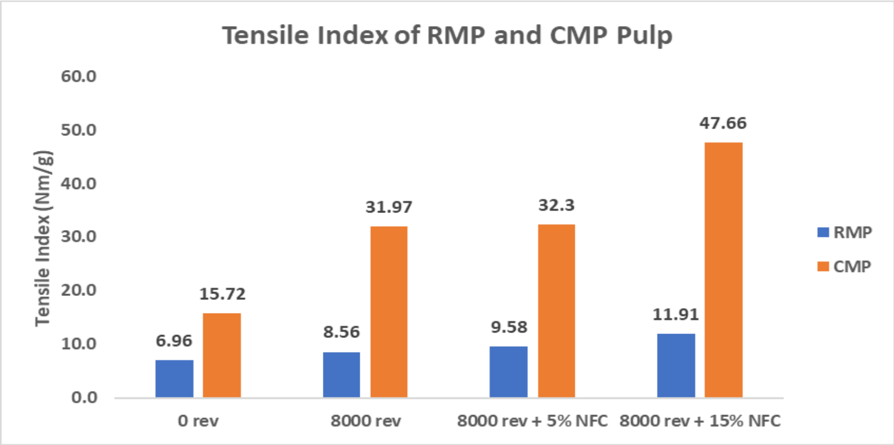

Figure 1: Tensile Index of RMP and CMP Pulp

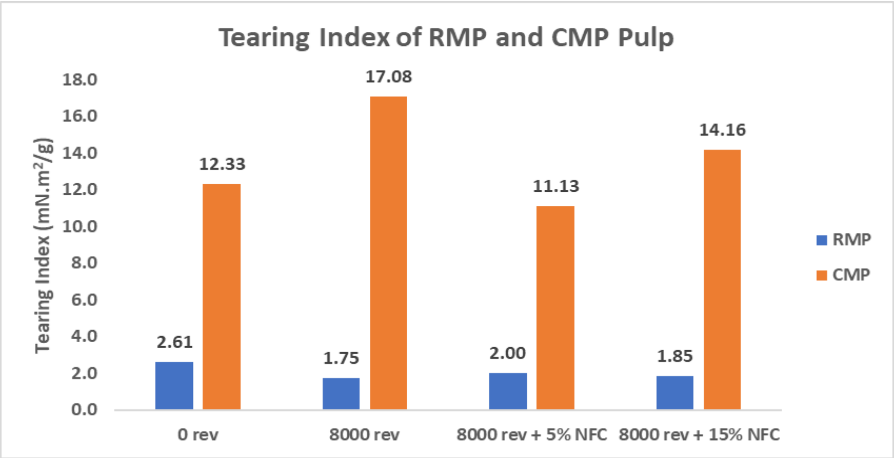

Figure 2: Tearing Index of RMP and CMP Pulp

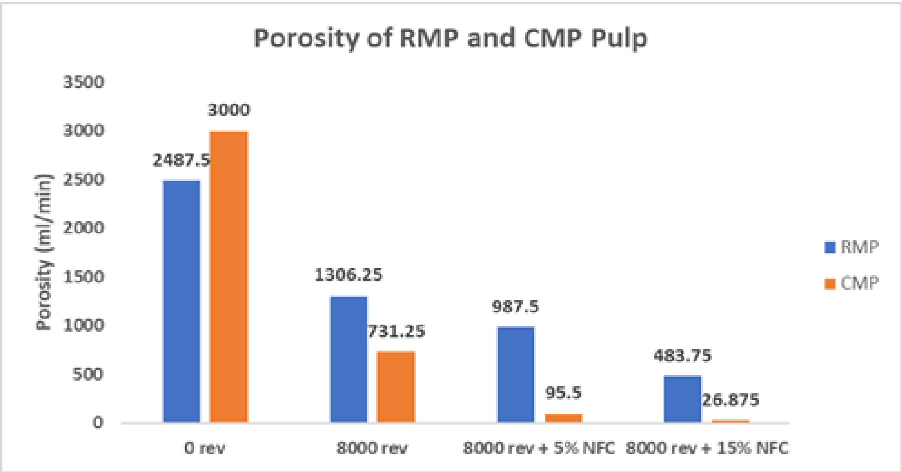

Figure 3: Porosity of RMP and CMP Pulp

4. Conclusions

This work demonstrates that nanocellulose can be mechanically extracted. The nanocellulose produced in this study was incorporated into paper production, and the results revealed several changes in the material's properties. The addition of up to 15% nanocellulose improves the tensile index and decreases porosity. However, no significant changes in the tearing index of the paper were observed. In terms of paper barrier properties, a reduction in air permeability of up to 90.7% was observed upon the addition of 15% nanocellulose to CMP paper. This discovery is highly significant for packaging papers used for food and pharmaceutical items because reduced air permeability inhibits microbiological growth, thus extending the product shelf life. This study has revealed the reinforcing ability of NFC from Buluh Semantan in improving the tensile index of paper products and reducing porosity. Future assessments should include additional mechanical tests such as burst and crush tests for a more comprehensive report.

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