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Cite as: AIP Conference Proceedings **2137**, 020008 (2019); https://doi.org/10.1063/1.5120984
Published Online: 07 August 2019

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Exploration of Tree Pruning Waste for Papermaking

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Abstract. The present study was conducted to explore the potential use of tree pruning waste as replacement material in papermaking. The investigation shows that the ultimate tensile strength and Young's modulus of the fabricated tree pruning waste papers are increased with the elevation of sodium hydroxide concentration, up to 20 % and 15 %, respectively. The morphological analysis confirms the performance improvement of tree pruning waste papers is achieved through the removal of lignin on the fibre surface. The sodium hydroxide concentration must be properly regulated to prevent the tree pruning waste fibres from degradation. The present study confirms the tree pruning waste holds immense potential to be used as the replacement material in papermaking, which, in turns, serve as a guideline to further diversify the use of tree pruning waste.

INTRODUCTION

Paper, a substance of many uses such as being made into tissues for cleaning, money for representing value and also corrugated box for packaging purposes. These papers normally made from wood by pressing hydrophilic cellulose plant fibres together and drying them into flexible sheets [1]. Paper has seen an increase from year to year by as much as 4 times in the past 50 years [2]. In the year 2014, paper production reached a new peak of 400 million tonnes globally where 67 % of them are mainly consumed by China, USA and Japan [3]. The paper production is expected to further increase and achieve at 521 million tonnes per year by 2021 due to the increase in demand [4].

The papermaking industry has a significant impact on the environment. This impart is due to the collection of the raw material, namely wood fibre, has resulted in deforestation since large amounts of trees has to be cut down in order to fuel this industry. This sentence is supported by the fact that 68 million trees per year is used to produce paper and paper product in the USA [5], which accounts for 35% of overall harvested trees. Therefore, some of the scholars have shifted their sights to investigate the use of non-wood fibre and biomass as an alternative material for papermaking. These materials including rice straw[4], bagasse [6], kenaf [7], tea waste[8], kapok fibre [8] and pineapple crowns [9].

Tree pruning waste is composed of leaves, branches and roots which produced from pruning trees to make sure the tree is healthy, free of safety hazards, maintains its natural form and also stimulate or restrict its growth. According to a survey [10], as much as 239.1 kg/day of wood waste was generated in Kuala Lumpur. This kind of solid waste is mainly found in parks, roads and fallen trees, which in turns, accounts for 12.4 % of the total waste generated in the capital city of Malaysia. Globally, it is estimated that only 13 % of tree pruning waste collected is utilized in the form of charcoal for energy generation. The remaining 87 % is discarded in landfill [11]. Incineration process has also been considered as one of the methods to dispose the tress waste. However, this method will result in the generation and release of greenhouse gases, and thus, global warming.

Proceedings of the International Engineering Research Conference - 12th EURECA 2019
AIP Conf. Proc. 2137, 020008-1–020008-6; https://doi.org/10.1063/1.5120984
Published by AIP Publishing. 978-0-7354-1880-6/$30.00

Tree pruning waste is as of yet unexplored material for papermaking. It is expected that the tree pruning waste will serve as an alternative method to reduce the aforementioned negative impacts from the pulp and paper industry; if it is determined to be feasible in being used for papermaking. Therefore, the objective of this research project is to investigate the use of tree pruning waste as replacement material in papermaking. The performance of the papers produced by using different sodium hydroxide concentration was assessed based on their tensile properties (ultimate tensile strength, Young's modulus) and morphology.

METHODOLOGY

Materials

Tree pruning waste was collected from the vicinity of Taylor's University as well as the housing area in Taman Mawar, Puchong, Selangor, Malaysia. The tree pruning waste was then grinded into small chips using a high power grinder. Analytical grade sodium hydroxide (purity > 95%) was purchased from Fisher Scientific.

Preparation of Tree Pruning Waste Papers

Firstly, pulping medium was prepared by dissolving the sodium hydroxide (5 %, 10 %, 15 %, 20% and 25% based on the mass of tree pruning waste) in 4 L of distilled water. After that, the solution was heated to and maintained within a temperature range of 80ºC − 90ºC. The tree pruning waste was added into the solution and cooked for 60 minutes. The tree pruning waste pulp was then filtered and dried in an oven at 60ºC. Subsequently, the dried pulp was softened by using water and spread over the wooden moulds to produce the tree pruning waste papers. Ultimately, the fabricated tree pruning waste papers were subjected to hot pressing process (75ºC and 5 tonnes) by using a hydraulic press.

Tensile Properties

The tensile properties (ultimate tensile strength and Young's modulus) of the fabricated papers were evaluated according to the ASTM D 828-97. The tensile properties of the papers (dimension: 7.06 cm × 1.50 cm) were measured by using an Intron universal tensile tester Model 5569 at 7.06 mm/min of crosshead speed. The measurement was repeated for ten times for each formulation and the average value was reported.

Scanning Electron Microscopy

The surface morphology of the tree pruning waste raw fibres and papers was examined by using a Hitachi S-3400N variable-pressure scanning electron microscope at an accelerating electron of 10 kV. The samples were coated with a thin layer of platinum using an auto fine coater before the surface examination (magnification: 100X).

RESULTS AND DISCUSSION

Tensile Properties

The tensile properties (ultimate tensile strength, Young's modulus) of the fabricated papers are illustrated in Fig. 1, 2 and 3, respectively. As shown in Fig. 1, the ultimate tensile strength of the fabricated papers is gradually elevated with the increasing of sodium hydroxide concentration. The papers with highest ultimate tensile strength (0.25 MPa) is produced when 20 % sodium hydroxide solution was used as the pulping medium. Nonetheless, the ultimate tensile strength of the papers start decreasing when the sodium hydroxide concentration is increased to 25 %. In fact, the elevation of the ultimate tensile strength is ascribed to the removal of lignin on the surface of the tree pruning waste fibres. The hydrophobicity of lignin prevents the formation of hydrogen bonds among the molecules of cellulose. Nonetheless, the utilization of sodium hydroxide solution as pulping medium can dissolve and remove the lignin from the tree pruning waste fibres. The efficiency of the lignin removal is even directly proportional to the concentration of the sodium hydroxide solution. Thus, the ultimate tensile strength of the papers will be significantly elevated to withstand the applied force when more hydrogen bonding can be formed among the molecules of cellulose.

The decrease in ultimate tensile strength at 25 % sodium hydroxide solution can be ascribed to the degradation of cellulose in the tree pruning waste fibres. The sodium hydroxide solution can remove the lignin without degrading the celluloses at mild alkaline conditions. However, under vigorous alkaline conditions, the inter-hydrogen bonds and intra-hydrogen bonds between the cellulose molecules can also be broken by the sodium hydroxide solution, which in turns, degrade and dissolve the cellulose into the pulping medium. This phenomenon reduces the molecular weight of cellulose in the tree pruning waste fibre, and thus, the ultimate tensile strength of the fabricated papers.

As shown in Fig. 2, the similar trending of the Young’s modulus is also observed when the concentration of sodium hydroxide is elevated in the pulping process. Initially, the Young’s modulus shows a gradual increase from 34.02 MPa to 88.78 MPa when the concentration was elevated to 15 %. However, adverse effect is observed on the Young’s modulus of the tree pruning waste papers when the concentration of sodium hydroxide solution was further increased to 20 % and 25 %. In fact, Young’s modulus measures the stiffness of a solid material based on the stress-strain relationship. The greater the value of Young’s modulus, the stiffer is the material. In other words, the optimum condition to produce the tree pruning waste papers with the highest stiffness is identified at 15 % concentration of sodium hydroxide solution.

The increase in Young’s modulus or stiffness of the tree pruning waste papers is attributed to the removal of amorphous deposits (hemicellulose and mainly lignin) on the cellulosic fibre surface. The removal of these amorphous lignin and hemicellulose results in a cleaner surface that retains the crystalline components in the fibre which strengthens the tree pruning waste. The similar observations was also reported when the Napier grass fibre was used as the material for papermaking [12].

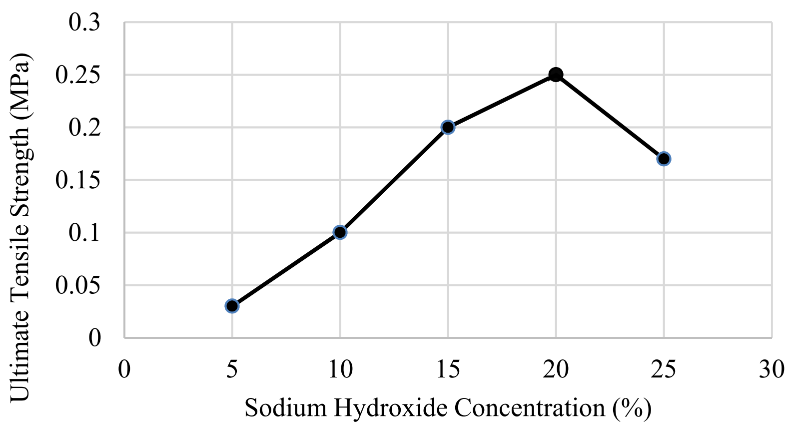

FIGURE 1. Ultimate tensile strength of papers fabricated at different sodium hydroxide concentration

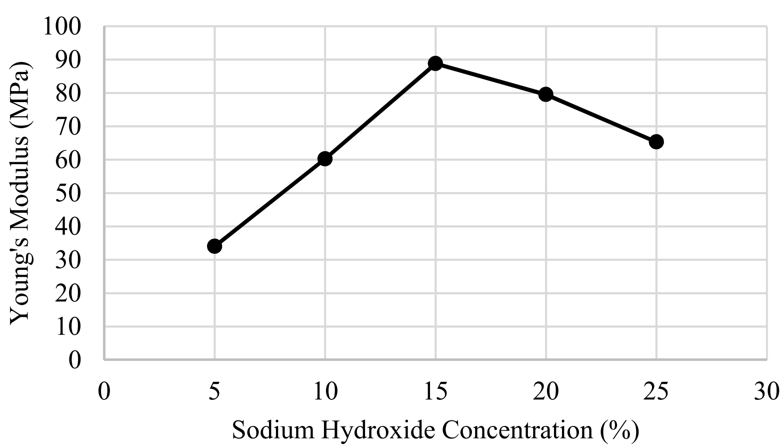

FIGURE 2. Young’s Modulus of papers fabricated at different sodium hydroxide concentration

Scanning Electron Microscopic Analysis

The surface morphology of tree pruning waste raw fibres as well as the papers (fabricated by using 20 % and 25 % of sodium hydroxide solution) are illustrated in Fig. 3, 4 and 5, respectively. Initially, the tree pruning waste raw fibres show a rough surface due to the adhesion of lignin. However, the pulping process has induced a smooth surface on the tree pruning waste fibres, as depicted in the scanning electron micrograph (Fig. 4). This observation implies that the use of 20 % sodium hydroxide solution has successfully remove the lignin from the fibre surface to facilitate the hydrogen bonding between the cellulose molecules in the fibres. The recorded scanning electron micrograph confirms the reported tensile properties in the previous section, whereby the papers with the optimum ultimate tensile strength can be produced by using 20 % of sodium hydroxide solution. On the other hand, the examination of the fibre (Fig. 5) that treated by using 25 % of sodium hydroxide solution reveals that the vigorous alkaline conditions has degraded the tree pruning waste fibres. The effect of fibre degradation is directly reflected by the decrease in the ultimate tensile strength of the fabricated papers in the present study.

CONCLUSION

In the present study, hand-sheets are successfully fabricated by using tree pruning waste as the raw material. The tensile properties, namely ultimate tensile strength and Young's modulus of the fabricated papers show an intimate relationship with the concentration of sodium hydroxide solution. The optimum ultimate tensile strength (0.25 MPa) and Young's modulus (88.78 MPa) of the tree pruning waste papers are obtained at 20 % and 15 % of sodium hydroxide concentration, respectively. The scanning electron microscopic analysis even suggests that the vigorous alkaline conditions should be avoid to prevent the tree pruning waste fibres from degradation. The current study confirm the tree pruning waste holds potential to be used as replacement material in papermaking. Nonetheless, further study should be conducted to further assess the performance of the tree pruning waste papers based on different aspects and properties.

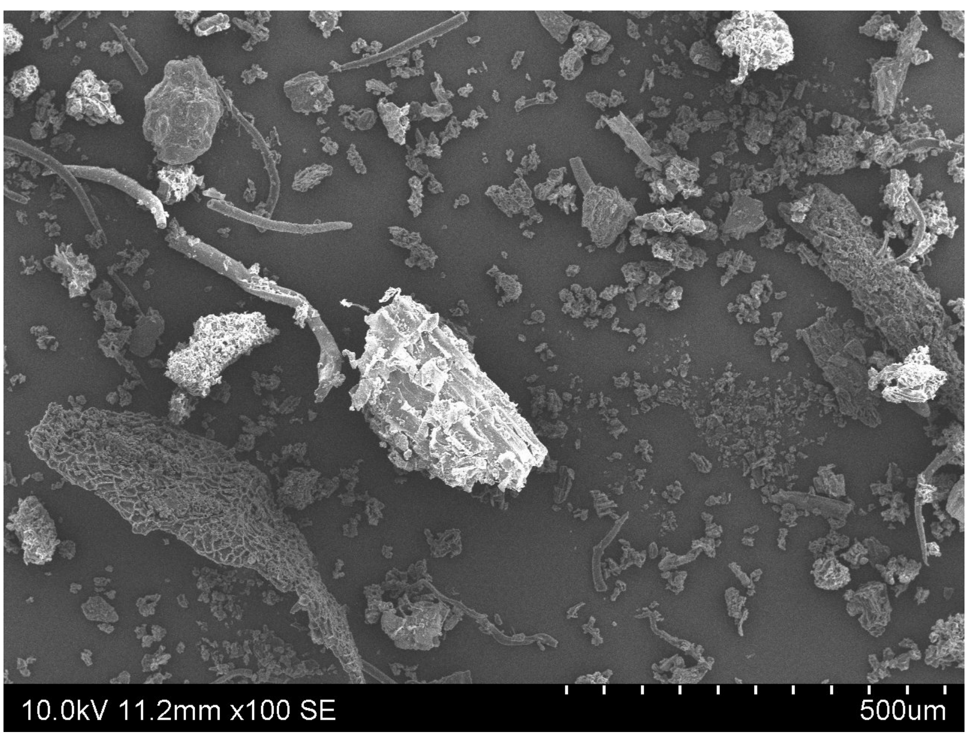

FIGURE 3. Scanning electron micrograph of tree pruning waste raw fibres

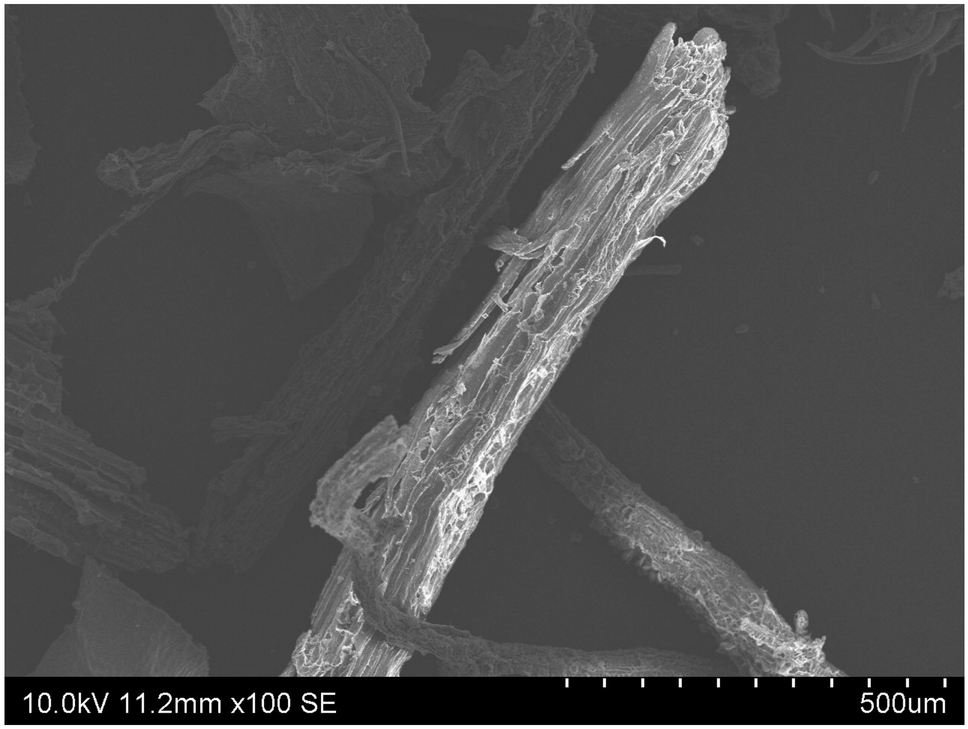

FIGURE 4. Scanning electron micrograph of papers fabricated at 20 % sodium hydroxide solution

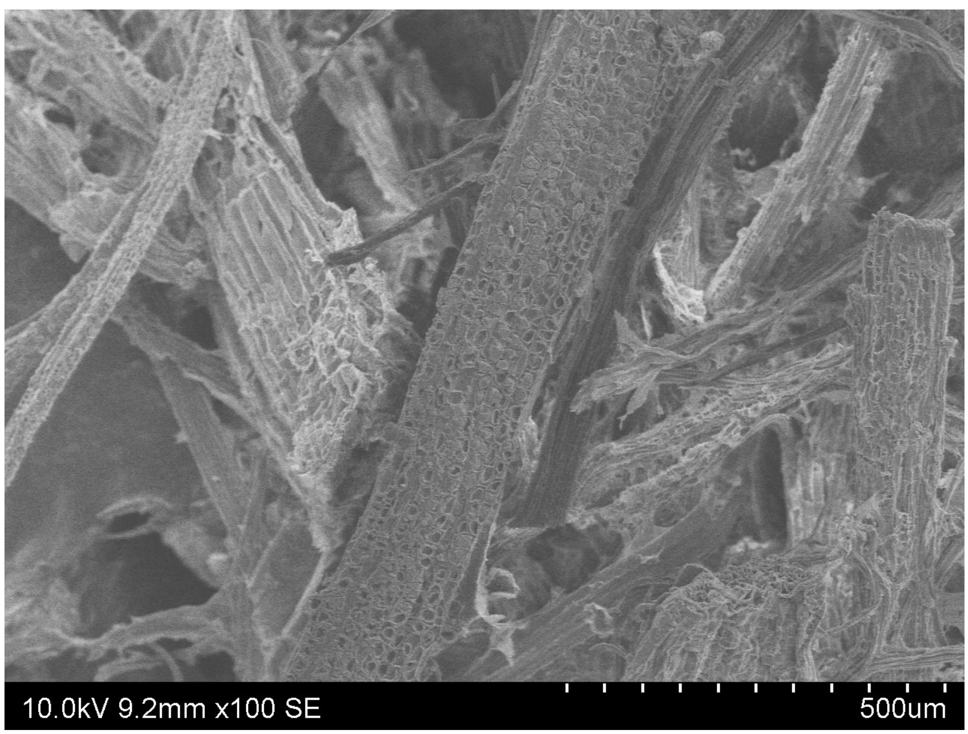

FIGURE 5. Scanning electron micrograph of papers fabricated at 25 % sodium hydroxide solution

ACKNOWLEDGEMENTS

We sincerely expressed our gratitude to Taylor's University to financially support the research project (Project Code: TRGS/ERFS/1/2018/SOE/030) through Emerging Research Funding Scheme (Budget Code: 320201-SR67-429-C31).

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