

Effect of chemical pretreatment on pulp and paper characteristics of bamboo *gigantochloa scortechinii* kraft fibers

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Abstract. In chemical pulping process, lignin is targeted to be dissolved and eliminated as much as possible in order to obtain better fiber separation. A primary study was carried out to investigate the effect of sodium hydroxide pretreatment prior to bamboo chemical pulping. The selected bamboo species was *Gigantochloa scortechinii* which is a well-known bamboo in Malaysia. The bamboo chips were soaked in 2 % sodium hydroxide solution for 6 hours at 60 °C. These treated chips were cooked at 14 % and 18 % of alkali active via kraft pulping process. The unbleached pulp was obtained and made into paper. The pulp and paper were tested according to pulp yield, pulp freeness, paper optical, paper physical and paper mechanical properties. The results exhibited that by using treated bamboo chips, the value of pulp yield, freeness and paper brightness increasing. Slight decrement was observed for mechanical paper properties such as tensile, tear and burst strength. Chemical pretreatment prior to pulping process was investigated to offer significant effects to the pulp and paper properties of bamboo *Gigantochloa scortechinii*. Hence, mild kraft pulping can be carried out to produce bamboo unbleached pulps. In addition, dependency on bleaching sequences can also be declined.

1. Introduction

Various chemical pretreatment methods have been developed and introduced such as acid, alkaline, lime, steam explosion and ionic liquid in order to pretreat lignocellulosic biomass. Lignin and hemicellulose can be partially removed by conducting pretreatment process. In addition, pretreatment also may decrease cellulose crystallinity and increase porosity of accessible surface area of biomass [1-2]. Pretreatment methods can be categorized as physical, physic-chemical, chemical, biological, electrical or combination [3-4]. Among these pretreatment methods, chemical pretreatment was examined and verified to be a promising one [5]. Therefore, it has becoming a promising method in order to remove lignin and/or hemicellulose, decrease degree of polymerization and reduce crystallinity of cellulosic components [6]. Hence, pretreatment process has been widely applied in pulp and paper industry specifically on the delignification of cellulosic materials [7].



The purpose of chemical pulping is to dissolve as much as possible lignin which binds the cellulose fibers. Hence, better fiber separation in terms of quantity or quality can be obtained. In pulp and paper technology, the choice of pulping process is identified based on final product, type of fiber and economic factors as well. Generally, there are 4 processes usually being used in pulping process, kraft, soda, sulfite and neutral sulfite semi-chemical process. Kraft pulping process is a process carried out in an elevated temperature and pressure in a solution of sodium sulfide and sodium hydroxide which dissolves lignin that contains in lignocellulosic materials. In producing chemical pulp of bamboo, kraft pulping is generally chosen compared to soda pulping [8]. The process offers acceptable delignification in terms of yield and viscosity. In addition, the reason kraft is suitable to bamboo is because of its fiber dimensions and chemical content resembles near to woods [8]. The kraft process provides satisfactory delignification as well as high yield and viscosity, but it also needs more bleaching agent due to darker pulp produced. The cooking condition is advised to be carried out at 16 % active alkali, 22 % sulfidity, 2.5 hours of cooking time at maximum 165 °C and liquor to wood ratio of 1:4.5 [9]. Thus, it is important to apply or combine several methods in order to reduce lignin content in biomass more economically and produce better quality of pulp [10].

Cell wall of plant is composed of three components namely as cellulose, lignin and hemicellulose. The most complexity structure and difficult to degrade is lignin. This is due to its high molecular weight and insolubility [11]. Hence, in the process of enhancing hydrolysis of cellulose, pretreatment of lignocellulose materials can be conducted in order to remove lignin and also hemicellulose content [12]. The pulp and paper miller applied both mechanical and chemical pulping processes to produce the desired pulps. Mechanical pulping process uses intensive electrical energy and produce paper of higher colour reversion rate due to the high content of lignin while chemical pulping needs excessive chemicals to degrade and dissolve the lignin which at the end leaving high strength cellulose fibers from cell wall. Nevertheless, chemical pulping produces lower yield [13].

Bamboo is a type of grass plant and most used as non-wood raw materials in the manufacturing of food, furniture, handicraft, construction, paper, board, textile, biomass energy [14], reinforcement fiber and more. In comparison to wood, bamboo may produce cellulose 2-6 times more [15] while its biomass increased by 10-30 % daily compared to wood biomass which increased by 2.5 % daily. Bamboo can be harvested after 4 years but wood trees need to wait 8-20 years before harvesting [15]. Bamboo species named *Gigantochloa scortechinii* which is well-known bamboo in Malaysia were used throughout this study.

Based on literature review, chemical pretreatment was introduced to woody materials. Looking at this matter, therefore a study has been conducted in order to determine whether the chemical pretreatment gives remarkable effects to the pulping and papermaking of bamboo.

2. Methodology

2.1 Materials

The bamboo stalks were obtained from Bentong, Pahang. These stalks were splitted into six strips prior to chipping process using Mini Chipper. These chips were then screened using Chip Classifier to a size of 2-3 cm in terms of width and length. The accepted size of bamboo chips was dried until 10 % moisture content in order to avoid any fungal attack. The chemicals used throughout the study were natrium hydroxide and sodium sulfite which were purchased from R&M Chemicals.

2.2 Pre-treatment of bamboo chips, kraft pulping and pulp testing

The bamboo chips were soaked in 2% sodium hydroxide solution for 6 hr at 60 °C. The pre-treated bamboo chips were then washed in order to remove soapy substance of natrium hydroxide. The pre-treated bamboo chips were placed into pulp digester and cooked for 120 min at 160 °C. The selected sulfidity was 25 % while the alkali active was at 14 % and 18 %. Two parameters of active alkali were selected in order to investigate the effect of alkali active concentration on pulp and paper properties of untreated and treated bamboo chips. Once cooking accomplished, the cooked pulp was washed and disintegrated using a hydropulper. The pulp at this stage is called unbleached bamboo pulp. The

unbleached pulp was then screened to separate any unwanted fibers in terms of length by using Somerville Screener. Finally, the accepted and rejected yields were calculated.

2.3 Beating of unbleached bamboo pulp and papermaking process

The beating was conducted using a PFI Mill which involved 24 g oven dried of unbleached pulp each time proceeding beating process. Before that, the pulp was dispersed in 2 L of distilled water. The dispersion was done in a British disintegrator until 3,000 rev for about 25 min. The dispersed pulp was later placed into the PFI Mill until 5000 rev. After completing the beating process, the beaten pulp was diluted in a pulp Stock Divider. The following steps were done according to TAPPI Standard T 205.

2.4 Paper Testing

Paper testing consists of physical, optical and mechanical paper properties. The physical paper test involved paper grammage and thickness. The optical paper properties comprise of paper opacity and brightness while mechanical paper properties include tensile, burst, tear and folding endurance. Standard methods referred throughout the experiments are listed as in Table 1.

Table 1. The standards applied for physical, optical and mechanical paper properties.

Paper properties	Name of test	Standard Method
Physical	Grammage	ISO 536-2012
	Thickness	ISO 534-1988
Optical	Opacity	T 425 om-01
	Brightness	T 425 om-02
Mechanical	Tensile	T 494 om-01
	Burst	T 403 om-97
	Tear	T 414 om-98
	Folding endurance	T 511 om-02

3. Results and discussion

3.1 Effect of chemical concentrations on pulp properties

The accepted pulp yield of chemical pulping process usually achieved about 40 to 50 %. This is different compared to mechanical pulping which pulp yield may reach up to 80 to 90 %. The results in Table 2 exhibited that by treating the bamboo chips prior to pulping resulted in significant affects to the accepted pulp yield. The pulp yield was improved for both 14% and 18% sodium hydroxide concentrations of 12.39 % and 31.05 % increment respectively. These can be allied to the function of sodium hydroxide which swollen the fibers directed to easier refining process. Due to this condition, the internal surface of cellulose will increase. The degree of polymerization and crystallinity of bamboo polysaccharides may decrease too [6]. These phenomena accumulated and promoted the cleavage of structural linkages between lignin and carbohydrate thus causes simultaneous disruption of lignin structure [16]. However, the pulp freeness showed increasing values which are expected to be lower than the freeness of untreated samples. In fact, the pulp freeness for 18% samples had no changes. This condition can be explained by referring to the condition of pulps. The pulps might be swollen but have high possibilities of flocking together which made these pulp flocs to pass through the refining part. On the other hand, this condition occurred might be due to high dose of chemicals had been introduced to pulps either during pretreatment or pulping processes. The ability of holding water by the pulp fibers are getting weaker which more towards drainage the water out from pulp slurry systems.

Table 2. The pulp yields and pulp freeness for untreated and treated samples of 14 % and 18 % soda pulping concentration.

Sodium hydroxide concentration	14 %		18 %	
Type of samples	Untreated	Treated	Untreated	Treated
Pulp screened yield, %	41.24	46.35	34.85	45.67
Pulp freeness, ml	410	535	560	560

3.2 Effect of chemical pre-treatment concentrations on paper optical properties

The opacity of the papers produced from both 14 % and 18 % pulping conditions were determined to be decreasing 4.64 % and 0.75 % accordingly. In contrary, the brightness of both treated samples increased 77.60 % and 2.30 % respectively. Huge increment of treated pulps at 14 % pulping condition can be associated to the disappearance of lignin content during pretreatment and pulping processes. Pulping process which involved sodium hydroxide as one of the pulping agent reduces amorphous hydroxyl groups from the fibers. This means that hydroxyl groups present in amorphous region act as hemicellulose and lignin were removed [17]. The decrement of hemicellulose and lignin may help to reduce the dependency on bleaching process in order to brightening the pulps for various products.

3.3 Effect of chemical pre-treatment concentrations on paper physical properties

Based on Table 3, grammage for 4 samples ranged from 67.34 g/m² to 69.96 g/m². These values showed weight of pulps or fibers that bonding together on 1 square meter of paper. The treated paper of 14% pulping condition provided highest grammage value compared to other samples. This result can be connected with thickness value which same sample showed highest value of thickness. Both thickness and grammage for paper produced from treated chips and undergone 14% pulping condition were recorded 190.43 µm and 69.96 g/m² accordingly.

3.4 Effect of chemical pre-treatment concentrations on paper mechanical properties

Based on mechanical properties showed in Table 3, both treated samples exhibited slight differences of result between each other. At the same time, both treated samples declined from untreated samples for tensile, burst and tear indices. The paper folding property presented extreme drop 53.68 % and 45.65 % for treated samples of 14 % and 18 % pulping condition respectively. This revealed that pretreatment was trivially done to the bamboo chips.

Table 3. The paper properties for untreated and treated samples of 14 % and 18 % soda pulping concentration.

Pulping concentration	14 %		18 %	
Type of samples	Untreated	Treated	Untreated	Treated
Physical				
Grammage, g/m ²	67.34	69.96	68.35	67.74
Thickness, µm	164.11	190.43	172.13	167.25
Optical				
Opacity, %	97.66	93.13	93.03	92.33
Brightness, %	22.23	39.48	37.73	38.60
Mechanical				
Tensile index, kN/m,	27.56	25.43	27.50	27.48
Burst index, kPa.m ² /g	2.95	2.78	2.76	2.80
Tear index, kN/m	2.63	2.59	2.77	2.60
Folding endurance	136	63	138	75

According to Lehto and Alen [16], kraft pulping involves three stages namely as extraction phase, bulk delignification stage and residual delignification. To relate, the bamboo chips was most probably have been over treated which involves all the three stages of pulping. The last stage that is called residual

delignification proceeding delignification slowly and loss of carbohydrate is increasing. It is estimated that prolong pretreatment with sodium hydroxide and proceeding with kraft pulping accelerated the dissolution of small amount of carbohydrate thus resulted in the slight decrement of paper strength. In other words, the pretreatment is entailed to break down the lignin structure and disrupt the crystalline structure of cellulose [17]. Therefore, the chemicals of pulping can easily access the cellulose to hydrolyze into monomers [18]. These conditions influenced the performance of fiber bonding that is proportionally relationship to paper strength. Looking at this matter, the fixed time for pretreatment should be revised to be less than 6 hours while the concentrations of sodium hydroxide as low as 1 or 1.5 % only.

4. Conclusions

Chemical pretreatment is found out to be one of the methods which can be introduced prior to pulping process. Based on the findings, it affected pulp and paper properties in all aspects. The point that can be highlighted was the increment of pulp brightness that was recorded as 77.60%. This showed that pretreatment method can be applied to reduce the dependency of bleaching sequences. In order to obtain better performance of pulp and paper properties, time of pretreatment and concentration of sodium hydroxide during pretreatment process should be perused and adjusted lesser.

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