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Characteristics of Pulp Produced from Refiner Mechanical Pulping of Tropical Bamboo (*Gigantochloa scortechinii*)

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ABSTRACT

Bamboo properties are somewhat similar to certain timbers but it has an advantage of having longer fibres, making it suitable for the production of pulp for paper and hardboard. However, the pulping process is a very crucial stage to produce fibres with an optimum quality. This study was carried out to characterize the pulp of *Gigantochloa scortechinii* using refiner mechanical pulping (RMP). The parameters evaluated included the effects of pre-treatment soaking in NaOH or steaming of chips and effects of refiner plate gap on pulp quality. Pulp quality was assessed based on the properties, yield, and lignin content of fibres. The pre-treatment with NaOH at 60°C for 6 h was found to produce superior quality pulp and lesser lignin content compared to pre-treatment by steaming at 150°C for 3 h. Meanwhile, the refiner plate gap test showed that the two cycles of refining (2.5-mm followed by 0.5-mm plate gap) reduced the lumpiness of the fibre, but it had lower felting power and Runkel ratio. Two cycles of refining process also led to higher fibre yield, produced more unbroken and slender fibres as compared to when one cycle treatment using 2.5-mm plate gap was used.

Keywords: *Gigantochloa scortechinii*, refiner mechanical pulping, bamboo pulp

INTRODUCTION

Bamboo has gained a great attention as potential raw material for wood-based industry in Malaysia. The bamboo plant can be harvested from its natural habitat or grown in a large scale (Azmy and Abd. Razak, 2000). *Gigantochloa scortechinii*, which is locally known as *Buluh semantan* is one of the most common species harvested and its use is mostly associated with traditional uses. Today, bamboo has been explored and expanded for high value-added products such as composites and laminated products. For a number of years, work has been carried out in bamboo producing countries to enhance the utilisation and range of products that can be manufactured from bamboo (Ganapathy, 1999).

Bamboo has the properties which are somewhat similar to certain timbers (Azmy and Abd. Razak, 2000), but it has an advantage of having longer fibres which makes it suitable for the production of pulp for paper and hardboard. However, bamboo is very hard compared to wood (Ganapathy, 1999*)* and its pulping process, especially when done mechanically, will impose problems if the material is not initially softened. A pre-treatment of the material is thus required prior to refiner mechanical pulping to obtain smooth and unbroken fibres for making hardboard (Kollmann *et al*., 1975). One of the

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common pre-treatments is the conventional steaming in which higher temperature and pressure are used to soften fibres. Nonetheless, this process will produce more brittles and higher amount of broken fibres after mechanical refining.

Another potential method is through mercerisation using sodium hydroxide solution. The alkali solution helps to degrade lignin and soften fibre physically and chemically (Sreekala *et al*., 1997). In particular, sodium hydroxide treatment functions as an irreversible mercerization effect to increase amorphous cellulose. This process is vitally important to yield high fibre recovery after refining and prevent fibre breakage or damage. In refiner mechanical pulping, besides pre-treatment process, the quality of pulp is also influenced by the gap of refiner disc plate. A high refiner plate gap will only produce loose fibres and the tendency to become lumpy is also greater, while smaller plate gap will lead to finer fibres, and hence reduce the yield.

This paper discusses the characteristics of pulp yielded from the pre-treatment of tropical bamboo (*Gigantochloa scortechinii*), either by steaming or by soaking in NaOH solution prior to refiner mechanical pulping (RMP). RMP was chosen in this study because it incurred lower cost as compared to chemical pulping and also prevented bamboo fibres from producing fines that could decrease the yield (Rowell *et al*., 2000) as well as hardboard strength (Beg and Pickering, 2004). The effects of refiner plate gap and the number of refining cycles on the properties of fibres are also reported.

MATERIALS AND METHODS

Materials

Fresh bamboo culms of *Gigantochloa scortechinii* Gamble (around 3-4 years old) were obtained from the Forest Research Institute Malaysia (FRIM) Research Plot at Chebar Besar Forest Reserve of Nami, in Kedah, Malaysia. A bamboo splitter that has eight fractions was used to split each culm into eight splits. The epidermis and nodal parts of the splits were removed using a single-faced planner. The bamboo strips produced had an approximate dimension of 20-mm (width), 4-mm (thickness), and 1000-mm (length), chipped to approximately 20 mm x 20 mm pieces and air-dried until equilibrium with the surrounding moisture content (MC). The air-dry MC of the chips was determined using the standard oven-drying method.

Mechanical Pulping of Bamboo Chips

The chips were divided into two batches. The first batch was steamed in a digester at 150°C with a pressure maintained at 5.95 kgcm^{-2} for 3 h. For this process (during the first 1 h period), the temperature and pressure were gradually increased, while the final temperature and pressure were maintained for the next 2 h. The second batch was soaked in 2% NaOH solution and maintained at 60°C (Sreekala *et al*., 2002) for 4, 6 or 8 h. The optimum soaking time for this treatment was evaluated. This is very important to prevent the fibre from being over-treated which could reduce its properties (Beg and Pickering, 2004). After soaking, the chips were washed thoroughly with cold water to remove sugars which could affect refining of chips (Rowell *et al.*, 2000).

The pre-treated chips were mechanically defibrated using a single disc refiner (Andritz Sprout-Bauer Model). The effects of the plate gaps and the number of refining cycles on the properties of fibre were also investigated. Three stages of refining were conducted with the disc plate gaps set between the refining plates at 2.5 mm, 0.5 mm and 0.1 mm, respectively. The preliminary results showed that with the use of 2.5 mm plate gap, the fibre yield recovery was approximately 60%, whereas those produced after refining at 0.1 mm plate gap size had only 40% fibre yield recovery. Thus, only the fibre morphology of the refined fibres, using 2.5 mm and 0.5 mm plate gaps, was analyzed. The refining process was performed in two different cycles; first with a refiner plate gap of 2.5 mm only, and secondly, initial refining using 2.5 mm, followed by 0.5 mm plate gaps. The purpose of the two-cycle refining was to reduce the adverse effect of harsh actions by the plates to the fibres. After refining, the wet fibres were manually squeezed to get rid of the water. Fibres from the untreated bamboo were macerated according to the standard laboratory manual and the data were used for comparison purposes.

Fibre Evaluation

Fibre yield recovery was determined by calculating the mean oven dry weight of the fibres yielded from the refiner per kilogramme of chips input. One g each of the wet fibres from different pre-treatments was stained in safranin 1%. They were then washed in alcohol series of 30%, 50%, 70%, and 95% alcohol each for 2 min, and finally with xylene. Several strands of fibres were placed on the slide, covered with a glass cover and labelled. The observations were made on a Leitz DMRB Image Analyzer which was attached to a digital camera. The length, diameter, and cell wall thickness of the fibres were determined by direct measurement of the magnified image of the fibres mounted on the slide. Fifty measurements were made from each of the five slides. Photographs of the sections (i.e. 20x magnification) were taken and printed.

The colour of the pulp was examined by comparing the pulp solution (10% w/v) from each process with Munsell Soil Colour Charts. Meanwhile, the lignin content of the pulp, together with the untreated bamboo, was determined according to the TAPPI Standard T222 OS-74 (Anonymous, 1974).

The analysis of variance (ANOVA) was performed on fibre property values to detect any differences between the pre-treatment processes and the numbers of refining cycles.

TABLE 1
Fibre properties of *G. scortechinii* yielded from different pre-treatments of chips followed by 2 cycles of RMP

Fibre characteristics	Pre-treatments				
	Steaming at 150°C and 5.95 kgcm^{-2}	Soaking in 2% NaOH at 60°C			Laboratory processed fiber
		4 h	6 h	8 h	
Fibre yield (%)	50.7c	65.2b	77.2a	74.6a	-
Length, L (mm)	1.45d	1.66c	1.96b	1.71c	3.20a
Width, D (µm)	26.84a	26.77a	26.77a	26.55a	20.64b
Cell wall thickness, w (µm)	5.51c	10.32a	10.76a	10.74a	6.90b
Lumen width, l (µm)	17.82a	6.14c	5.25d	5.07d	14.04b
Felting power (L/D)	54	62	73	64	156
Runkel ratio ($2w/l$)	0.62	3.36	4.10	4.24	4.17
Lignin content (%)	25.67a		19.90b		26.94a
Colour of fibre solution	Dark brown		Yellow		Pale yellow

Means followed by the same letter are not significantly different at $p < 0.05$ using LSD

RESULTS AND DISCUSSION

The results for the fibrous properties of *G. scortechinii* from different pre-treatment processes, followed by 2 cycles (2.5-mm plate gap followed by 0.5-mm plate gap) of the mechanical pulping, are shown in Table 1. The properties of fibres resulted from refining using different plate gaps are given in Table 2.

Effect of Pre-treatments on Fibre Properties

In this study, the fibre recovery from the steam pre-treatment of bamboo (50.7%) was lower than NaOH pre-treatment (65.2- 77.2%). In particular, soaking in NaOH for 6 h yielded the highest recovery. A higher percentage of broken fibres was found in the steam-treated bamboo and the fibre produced was rather rigid (*Fig. 1a*). This was probably attributed to the lignin which was still present in a large quantity (25.67%) in the loose fibre. The lignin content in the untreated bamboo was found to be around 26.94%, while the lignin content in NaOH-treated fibre was 19.9% (Table 1). The results reflected that the steaming temperature used in this study (150°C) was insufficient to degrade the lignin from the fibre (Suchsland and Woodson, 1991; Sjostrom, 1993). Both the thermal and mechanical actions involved in the pulping process could also lead to the brittleness of the fibre, causing it to collapse easily and form fines. Steaming process has also been found to produce lumpy fibres. This is a result of flocculation where water content in the fibres is relatively higher, and thus making them more absorbent or hydrophilic. Unlike the steam pre-treated fibre, fibres which were pre-treated with NaOH were hydrophobic. The treatment had partially removed lignin and hence produced microfibril with greater crystallinity.

The high fibre recovery from the NaOH pre-treatment is partly due to the effectiveness of this particular process in changing cellulose I to cellulose II, resulting in increment of crystalline fibre chain and reduction of amorphous line. Natural cellulose has cellulose I crystalline structure, but on alkalisation, it changes to cellulose II, in which the parallel polymer chains of cellulose I was aligned anti-parallel and higher exposition of OH^- (Vilaseca *et al*., 2006). The high content of hemicellulose, coupled with the reduction of lignin during alkalisation, would contribute to more fibres being easily extracted from the treated chips. Pickering *et al*. (2006) found that chemically processed fibre was 32% richer in cellulose as compared to the non-chemically processed fibres. NaOH pre-treatment helps swelling the fibrils and also

TABLE 2
Fibre properties of *G. scortechinii* chips produced after refining at different cycles

Fibre morphology	Refiner plate gap size (mm)			
	Steaming at 150°C and 5.95 $kgcm^{-2}$		Soaking in 2% NaOH at 60°C for 6 h	
	1 cycle	2 cycles	1 cycle	2 cycles
Length, *L* (mm)	2.39a	1.45b	2.18a	1.96b
Width, *D* (micron)	26.58a	26.84a	26.63a	26.77a
Cell wall thickness, *w* (µm)	4.80b	5.51b	10.72a	10.76a
Lumen width, *l* (µm)	18.98b	17.82b	5.19a	5.25a
Felting power (*L*/*D*)	90	54	82	73
Runkel ratio (2*w*/*l*)	0.51	0.62	4.13	4.10

Means within the pre-treatment followed by the same letter are not significantly different at $p < 0.05$ using LSD cleaning the fibre bundle surface (*Fig. 1b* and *c*), and as a result increased the tensile strength of the fibre. As the fibre strength improved and became more plastic, it would not be easily damaged by mechanical pulping and more fibre could be extracted (Pickering *et al*., 2006; Mwaikambo and Ansell, 2003).

The results also showed that the quality of fibre from NaOH pre-treatment was dependent on the soaking time. The longest fibre was recorded from 6 h soaking (1.96 mm) and the shortest was in 4 h (1.66 mm). Nonetheless, prolonging the soaking time to 8 h did not significantly affect the length of fibre (1.71 mm). The steam treatment was found to produce shorter fibre (1.45 mm) as compared to the NaOH treatment. The high variation of fibre length in the steam treatment (71.1%) indicated that the fibres were broken during pulping (*Fig. 1a*), as a result of embrittlement of the fibres caused by the application of high temperature (150°C) and pressure (5.95 kgcm^{-2}). Generally, the mechanical pulp had fibres shorter than the actual fibres produced using the laboratory mercerisation process (i.e. 3.20 mm).

Regardless of the pre-treatment process, the width of fibre produced by RMP was relatively similar, i.e. between 26.55-26.84 µm. These values were relatively higher than the fibres extracted in the laboratory. Similarly, the thickness of the cell wall for the NaOH-treated fibre (10.32-10.74 µm) was significantly higher than that of the fibre which was produced in the laboratory (6.90 µm). A similar observation was reported by Mwaikambo and Ansell (2003). The NaOH treatment was found to help the cell wall to swollen and to produce fibre with small lumen size known as closed lumen (*Figs. 1b* and *1c*). An internal fibrillation of the cell wall was also noticed in the NaOH-treated fibres (*Fig. 1d*). Lignocellulosic fibre is usually packed with microfibrils but it was split after the alkali treatment (Cao *et al*., 2006). This phenomenon is termed as fibrillation that breaks the treated fibre bundle down into smaller ones by the dissolution of the hemicellulose. Fibrillation

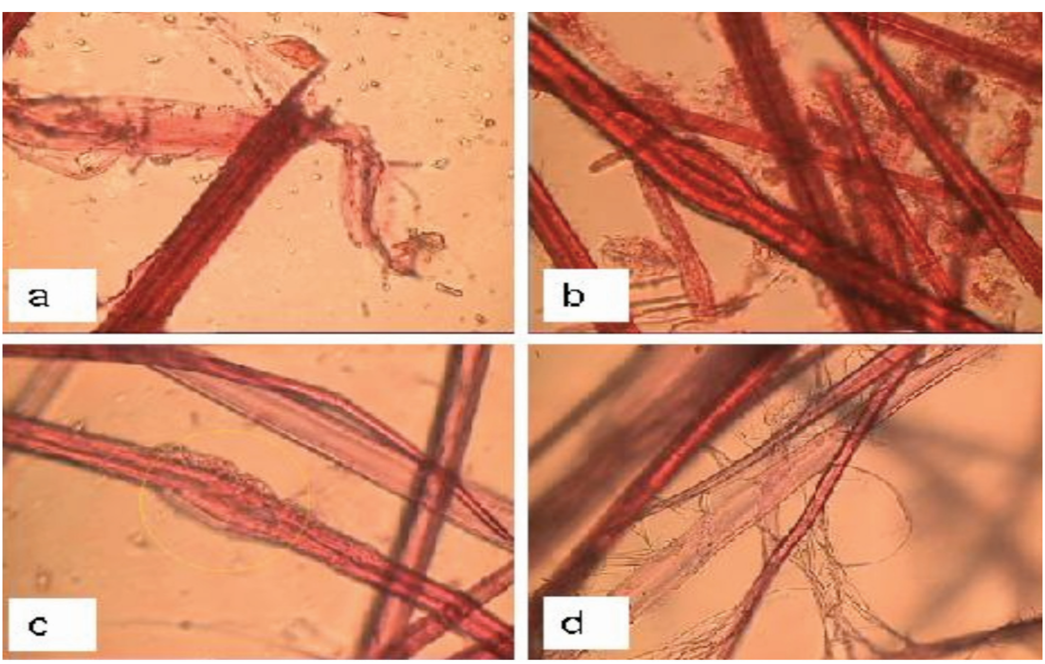

Fig. 1 (a): Broken fibre from steam-treated chips, (b) Swollen unclean surface fibre from 4 h-NaOH-treated chips, (c) Swollen clean surface fibre from 8 h-NaOH chips, and (d) Fibrillation of fibres from NaOH-treated chips has the advantage of increasing the surface area available for contact with the matrix and hence improving the interfacial adhesion (Bisanda and Ansell, 1992).

Higher felting power results in a better fibre-matrix adhesion (Gassan and Bledzki, 1999; Mwaikambo and Ansell, 2003; Cao *et al*., 2006). Fibre with high felting power indicated that the fibres produced are very slender (long and thin fibres) and with good pulp quality (Britt, 1970). The felting power of the steam-treated fibres was 54 and this was 73 for the NaOH-treated fibre. The values are very much lower as compared to the laboratory produced fibre (146), but it is similar with the range values for the southern pine (28-440) (Sjostrom, 1993). The results also suggested that the felting power for the mechanical pulping bamboo fibre would give a good interfibre bonding in the production of paper or hardboard. The NaOH-treated fibres had high Runkel ratio (i.e. with 4.10), while steam-treated fibres had 0.62. Meanwhile, the Runkel ratio of the untreated fibres was 4.17.

As for colour, the solution of steam-treated fibre is darker (dark brown) than NaOH-treated fibre (yellow), while the solution of the untreated fibre has a yellowish colour when the Munsel Soil Colour Chart was used as a reference. The darker colour found in the steam-treated fibre is partly due to the heat and pressurised system in the process which decolourises the fibres, and this may probably be due to the high amount of lignin retained in the fibres (25.67%). Fengel and Shao (1985) reported that lignin softens and becomes thermoplastic at 90°C, while degrades and dissolves when the temperature reaches 170°C. However, the temperature used in this study was only 150°C which maintained the lignin in a plastic form in the fibre structure (Hsu *et al*., 1986). In this study, the NaOH treatment was found to remove only 7.04% lignin from the bamboo. Therefore, the low concentration of NaOH solution (2%) used in this study might not be sufficient enough to degrade all the lignin. Nonetheless, the treatment with 5% NaOH successfully removed a great amount of lignin from palm fibres (Geethamma *et al*., 1995), while the treatment with 6% NaOH removed lignin of hemp, jute, sisal, and kapok fibres (Mwaikambo and Ansell, 2003).

Effect of Refiner Plate Gap on the Properties of Fibre

Adjustment of refiner plate gap would vary the size of the fibre bundles of wood (Blomquist *et al*., 1981). The effects of refiner plate gap on the fibre properties are shown in Table 2. In general, chips which underwent one cycle of refining had a higher fibre length than those refined for two cycles, regardless of the pre-treatment. The pulps produced, however, were lumpy (*Fig. 2*). For the steam-treated chips, the length of fibre was reduced from 2.39 mm to 1.45 mm, when they were refined from one cycle to another. Those treated with NaOH for 6 h produced fibre with the mean lengths of 2.18 mm and 1.96 mm when refined for one and two cycles, respectively. Wood fibre has been reported to be easily damaged by the rotating knife when it was first treated with steam (Das *et al*., 2000).

The diameters of fibre from both the pre-treatments were not significantly different from each other. The values ranged from 26.22 to 26.84 µm. Meanwhile, the thickness of the cell wall of the NaOH-treated fibre which underwent one cycle and two cycles of refining was similar (10.72-10.76 µm). However, steam-treated fibres with two cycles of refining had a thicker wall (5.51 µm) as compared to a single cycle of refining (4.80 µm). The increment in the thickness of the cell wall after the second refining was attributed to the flattening or collapse of fibre due to the narrow gap of plate action. Clark (1985) revealed that the high temperature steaming, coupled with the harsh action of refiner plate gap, would easily cause fibre to collapse. Regardless of the pre-treatment, the felting power of the fibre was adversely affected by the number of refining cycles. A higher felting power (90) was found on the steam-treated fibre which had undergone 1 cycle of refining. It was decreased to 54 when refined with a smaller plate gap. The same result was

Fig. 2. Fibres from two cycles (2.5-mm plate gap followed by 0.5-mm) of refining (left) and Lumpy fibres from one cycle (0.5-mm plate gap) of refining

observed for the NaOH-treated fibres, where two cycles of refining produced a higher felting power fibre (82) than that of one cycle (73), but with insignificant variation as compared to the steam-treated fibre. The Runkel ratios of the NaOH-treated fibre, with one and two cycles of refining, are similar (i.e. between 4.10-4.13) and these values were markedly higher than the steam-treated fibre where the values are 0.51 and 0.62 for one and two cycles, respectively.

CONCLUSIONS

The pre-treatment of *G. scortechinii*, prior to mechanical pulping, was found to significantly affect the pulp properties. The results showed that soaking bamboo in 2% NaOH solution maintained at 60°C produced higher fibre recovery, superior quality, and lighter pulp colour than those which were pre-treated by steaming at 150°C for 3 h. Within the NaOH treatments, bamboo soaked for 6 h produced an optimum pulp quality compared to 4 and 8 h soakings. In the refiner plate gap test, two cycles of refining (2.5 mm followed by 0.5 mm plate gap) reduced the lumpiness of the fibre, but it had a lower felting power and Runkel ratio compared to the one-cycle refining (2.5 mm plate gap). This treatment also resulted in higher fibre yield, produced more unbroken and more slender fibres than the one-cycle treatment. The results also revealed that an optimum quality of mechanical bamboo pulps for hardboard production could be obtained through pre-treatment of chips by soaking in 2% NaOH for 6 h, followed by 2 cycles of refining (first with 2.5-mm and followed by 0.5-mm plate gaps).

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