Effect of Beating Revolution on Sweet Bamboo (*Dendrocalamus asper* Backer) Kraft Pulp Properties

Suphat Kamthai[1]* and Pratuang Puthson[2]

[1]*Department of Packaging Technology, Faculty of Agro-Industry ,Chiang Mai University, Chiang Mai 50100, Thailand*

[2]*Pulp and Paper Technology, Department of Forest Products, Faculty of Forestry, Kasetsart University, Bangkok 10903, Thailand*

**Corresponding author. E-mail: SuphatK@chiangmai.ac.th, Suphat_61@hotmail.com*

ABSTRACT

Chips of sweet bamboo were delignified by kraft pulping process. The obtained pulps were evaluated for unbleached pulp properties by beating effect. Considering the kraft pulping process, it was found that the effluent of active alkaline level could change pulp yield and kappa number. At similar 30% sulfidity and different (16–22%) active alkaline, the active alkaline charge was increased and screened yield and kappa number were decreased. When active alkaline increased 2 %, the pulp yield and kappa number decreased and about 2%. The highest sweet bamboo screened yield and kappa number were 46.32% by 12.5 points. It was selected to evaluate beatability and strength of unbleached sweet bamboo kraft pulp by PFI mill. The data presented the beating revolutions which importantly affected all pulp strengths and slightly affected optical properties as brightness. At 4000 rev. and freeness 388 ml,CSF it illustrated the highest tensile strength, 70.20 Nm/g and tear strength, 35.82 mN.m^2/g. In contrast, the highest burst strength and folding endurance were indicated at 5000 rev. and 300 freeness ml,CSF. They were 4.10 kPa.m^2/g and 492.20 r/c, respectively. The optical property of unbleached sweet bamboo kraft pulp was low brightness and was about 20% ISO.

Key words: *Dendrocalamus asper* Backer, Sulfidity, Active alkaline, Kappa number, Screened yield, Beatability

INTRODUCTION

The lack of long fiber support in Thailand's pulp and paper industries should be seriously considered. Although short fiber pulp can be locally produced, long fiber pulp must be imported. It is 100% imported, mainly from Canada, Chile, USA and South Africa. The long fiber pulp demand recently was 205,000 ton, 2% raised from 2000. The prediction of pulp and paper demand in next four years is expected to grow by 4% per annum (Thai Pulp and Paper Industries Association, 2001). Thus, the new long fiber resource for pulp and paper production is pointed towards non-wood plant such as bamboo which can be made available for pulp and paper industries.

Bamboo is one of the socio-economic plant species in Thailand. It is used for many purposes such as food, household construction, furniture and pulping. The most popular and available bamboo type is sweet bamboo which occupies about 153,227 rai (24,516 ha) (Pungbun Na Ayudhya, 2000). Kamthai (2003) reported the approximate fiber dimensions of sweet bamboo as: length 3.11 μm, fiber width 18.03 μm, lumen width 4.35 μm and cell wall thickness 9.68 μm. It has long fiber and very thick wall. From sweet bamboo, fiber morphology can predicted, its pulp can be produced with high strength properties as well as softwood pulp. However, their properties depend on pulping process, pulping condition and beating requirement.

The most popular pulping process in the world is sulfate or kraft pulping process because of its excellent pulp strength and its easy recovery of chemicals. Today, the kraft process is not only a dominant alkaline pulping process for wood, but also the mostly-used pulping process for non-wood as bamboo. The process involves cooking the wood chips in a solution of sodium hydroxide (NaOH) and sodium sulfide (Na_2S) at pH 12, 160–180°C, corresponding to about 800 kPa (120 psi) steam pressure, for 0.5–3 hour to dissolve much of lignin of wood fiber (Biermann, 1993). Casey (1979) reported that kraft cooking condition normally used active alkaline 14–22% on dry weight of chip and sulfidity 20–25% and indicated kraft is good process for bamboo pulping. Particularly, bamboo has the dense-texture chip, which is not difficult to absorb the pulping white liquor. Thus, sweet bamboo can pulp with this process for desired pulp quantity by beating.

The objectives of this work were: (1) to optimize pulping processes with high pulping yield and give suitable kappa number (2) to evaluate properties of obtained pulp from kraft pulp and (3) to investigate the effect of beating revolution on strength improvement.

MATERIALS AND METHODS

Raw Material Preparation

Sweet bamboo, 3-years-old, from bamboo plantation in Prachinburi province was used in this study. The bamboo culms were selected and cut at 0.30 m above ground. For pulping experiment, sweet bamboo culms were chipped and screened through 19–25 mm hole screen. The accepted chips (proper size) were left on the 22 mm and under 19 mm hole screen. The moisture content of screened chips was determined, using TAPPI T208 om-94. Then sweet bamboo chips were packed in plastic bag around 700 g, oven-dry weight.

Pulping Processes

Cooking method in this study was kraft pulping. The white liquor of kraft pulping was prepared from commercial sodium hydroxide (NaOH) and sodium sulfide (Na_2S) and analyzed according to SCAN-N 2:88. The 700 g oven-dry weight chips were cooked in a 7-liter rotating digester by kraft conditions. They are listed in Table 1.

After pulping, brown stock was washed with excess tap water and mechanical disintegrator disintegrated pulp. Then cooked pulp was screened with screen plate with slots of 0.15 mm (TAPPI T275 sp-98) and separated for screened yield and yield reject. The yield obtained was estimated for kappa number (TAPPI T236 om-99) and determined for dry matter content of screened yield and reject (TAPPI T208 om-94). The pulp yields and reject content, as percentage on an oven-dry weight, were calculated.

Table 1. Cooking conditions of kraft pulping.

Cooking conditions	Kraft
Active alkaline (%) as O.D. weight	16–22
Sulfidity	30
Liquor to wood ratio	4 : 1
Time to max. temperature (min)	60
Time at max. temperature (min)	90
Max. temperature (°C)	170

Testing of Papermaking Properties

The unbleached pulp was beaten in PFI mill according to TAPPI T248 sp-00. Freeness and pulp physical properties demonstrated the effects of beating levels and papermaking properties. Freeness of beaten pulps was measured according to TAPPI T227 om-99. The handsheet for testing of papermaking properties was formed according to TAPPI T205 sp-02. The handsheet of each beating condition was measured for optical and strength properties such as brightness (TAPPI T452 om-98), basis weight or grammage (TAPPI T410-om-98), thickness (TAPPI T411 om-97), density and bulk (TAPPI T426 wd-70), tensile strength (TAPPI T494 om-96), tearing strength (TAPPI T414 om-98), bursting strength (TAPPI T407 om-97) and folding endurance (TAPPI T511 om-02).

RESULTS AND DISCUSSION

Kraft Pulping

All cooking results from sweet bamboo kraft pulping are presented in Table 2. The experiment studied the effluent of active alkaline level on pulp yield and kappa number. Consequently, active alkaline charge increased by about 2% and screened yield and kappa number also decreased by 2%. Figure 1 shows the relationship between kappa number and screened yield. The results show the highest pulp yield and kappa number of 46.32% and 12.54 respectively from the 16% active alkaline. At 22% active alkaline, the lowest pulp yield was 41.10% and the lowest kappa number was 8.53.

Table 2. The results of bamboo kraft pulping.

Process	Condition	Screened yield (%)	Kappa number
Kraft	S30 - A16 - 60 - 90 -170 -4:1	46.32	12.54
	S30 - A18 - 60 - 90 -170 -4:1	43.25	10.57
	S30 - A20 - 60 - 90 -170 -4:1	42.66	8.39
	S30 - A22 - 60 - 90 -170 -4:1	41.10	8.53

Discussed about bamboo pulping process, Hurter (1991) reported that the bamboo kraft pulping had unbleached pulping yield about 46–47 %. Sadawarte et al. (1982) indicated bamboo kraft cooking result at 16% active alkaline and 20% sulfidity that it had high yield pulp, 43.7% and 37.6 kappa number. The Muli bamboo (*Melocanna baccifera*) kraft pulping was investigated by Feng and Alen (1998). They reported that at high active alkaline level, it resulted in high kappa number and screened yield. Sweet bamboo kraft pulping could be produced with higher pulp yield and lower kappa number than other bamboo species. Unbleached sweet bamboo kraft pulp was selected to evaluate pulp properties that had high screened yield.

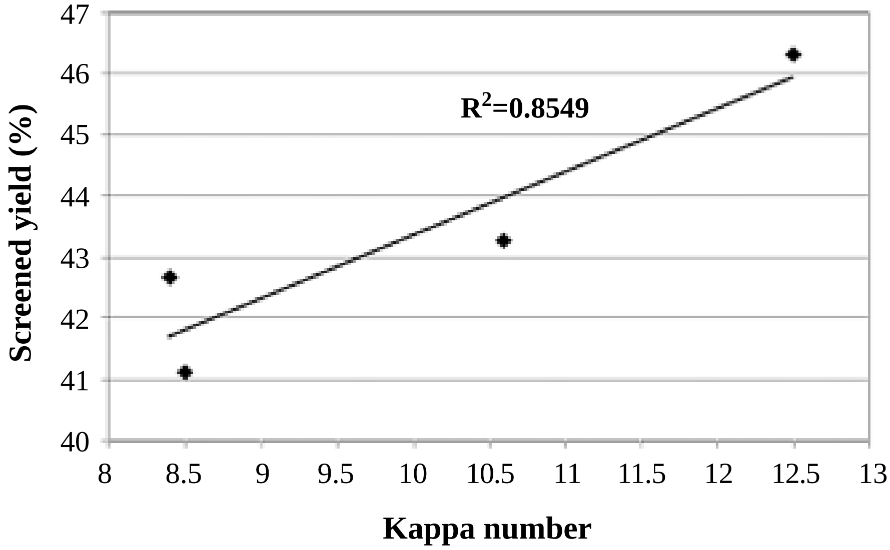

Figure 1. Kappa number and screened yield of unbleached sweet bamboo kraft pulps.

Pulp properties

The pulp properties of unbleached sweet bamboo kraft pulp are revealed in Table 3. In this section, its beatability was considered after beating by PFI mill. In Table 3, beating revolutions strongly affected pulp strength and slightly affected optical properties such as brightness. Biermann (1993) reported that strength of paper increased with pulp beating or refining since it relied on fiber-to-fiber bonding.

Table 3. Unbleached sweet bamboo kraft pulp properties.

Pulp Properties	Beating Rev. by PFI mill						
	0	1000	2000	3000	4000	5000	6000
Freeness (ml, CSF)	743	670	582	488	388	300	210
Basis weight (g/m^2)	58.32	59.10	58.91	58.21	58.95	56.42	56.95
Thickness (mm)	0.20	0.18	0.18	0.18	0.17	0.15	0.17
Density (g/cm^3)	0.29	0.32	0.32	0.33	0.34	0.38	0.34
Bulk (cm^3/g)	3.47	3.10	3.13	3.01	2.93	2.63	2.97
Tensile Index (Nm/g)	22.44	33.96	52.49	63.01	70.20	59.68	40.41
Tear Index ($mN.m^2/g$)	10.29	25.76	27.44	34.20	35.82	34.64	33.60
Burst Index ($kPa.m^2/g$)	0.62	2.05	2.09	3.19	3.96	4.10	3.98
Folding endurance (r/c)	0	24	66	217	358	492	349
Brightness (%ISO)	20.98	19.87	20.00	19.67	19.63	19.43	20.34

Beatability and Drainability Development

The influence of beating level on drainability of unbleached sweet bamboo kraft pulp is presented in Figure 2. Its drainability reduced and also did freeness value. Smook (1997) reported that kraft pulps were more difficult to beat; required more energy than sulfite pulp.

Thus, it means that the cooking method has a major effect on beatability. From this experiment, the highest beating revolution was 6000 and the lowest freeness was about 200 ml, CSF. However, this beating level did not increase the surface area and resulted in the reduction of fiber-to-fiber bonding and hence, affecting paper properties.

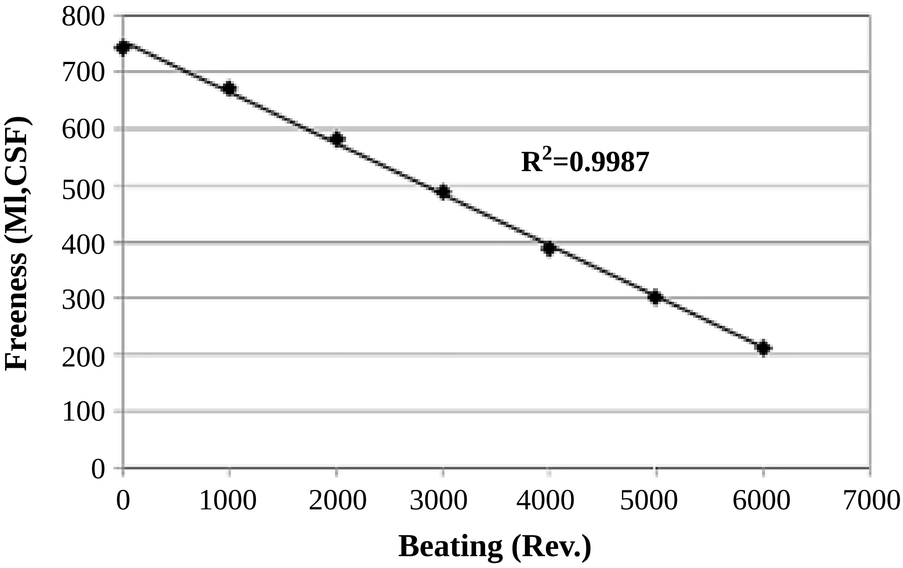

Figure 2. The relationship between freeness and beating levels of unbleached sweet bamboo kraft pulp.

Discussing the effect of beating on fiber surface area, Biermann (1993) presented the action of beating or refining on fibrillation, i.e., exposure of cellulose fibrils to increase the surface area of the fiber. For example, the surface area of softwood kraft fiber is in the order of 1 m^2/g at 750 ml, CFS but it increases to about 5 m^2/g at 350 ml, CSF. After that fiber-to-fiber bonding was improved. Compare to unbleached bamboo kraft pulp, at the freeness about 350 ml, CSF it occurred at 4000 beating revolution.

Basis weight and Thickness

The basis weight of unbleached sweet bamboo kraft pulp was influenced by beating level. It was 56.42–59.10 g/ m^2. In case of thickness, results were 0.15–0.20 mm and it was reduced when the beating revolution increased and freeness decreased. The beating revolution affected individual fiber that could make fiber shorten, reduce cell wall thickness and more fibrillation when beaten fibers were bonded together. The pulp properties will develop and drop until over-beating level. For example, basis weight is low and paper is thin if beating revolution is much more than 6000 rev. The Figures 3 and 4 show the relationship between beating revolution and basis weight and thickness of unbleached sweet bamboo kraft pulp respectively.

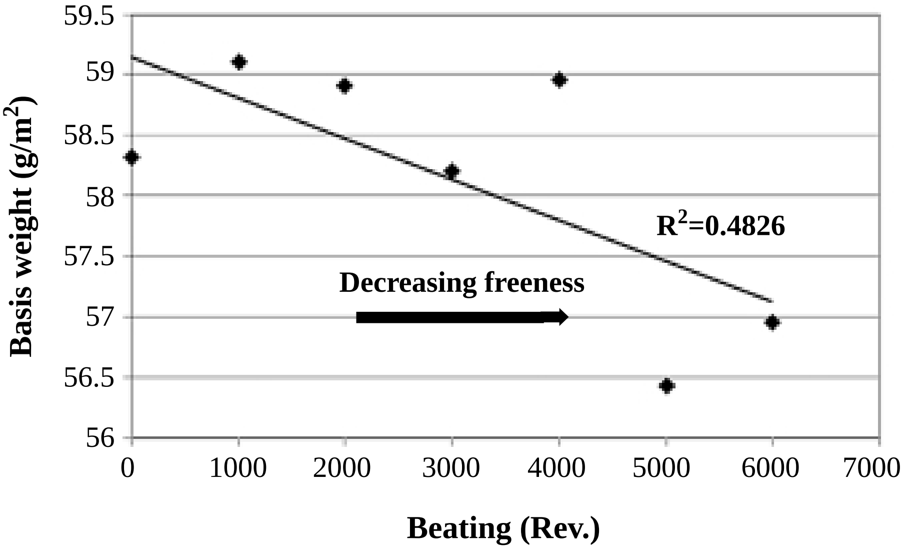

Figure 3. The relationship between basis weight and beating levels of unbleached sweet bamboo kraft pulp.

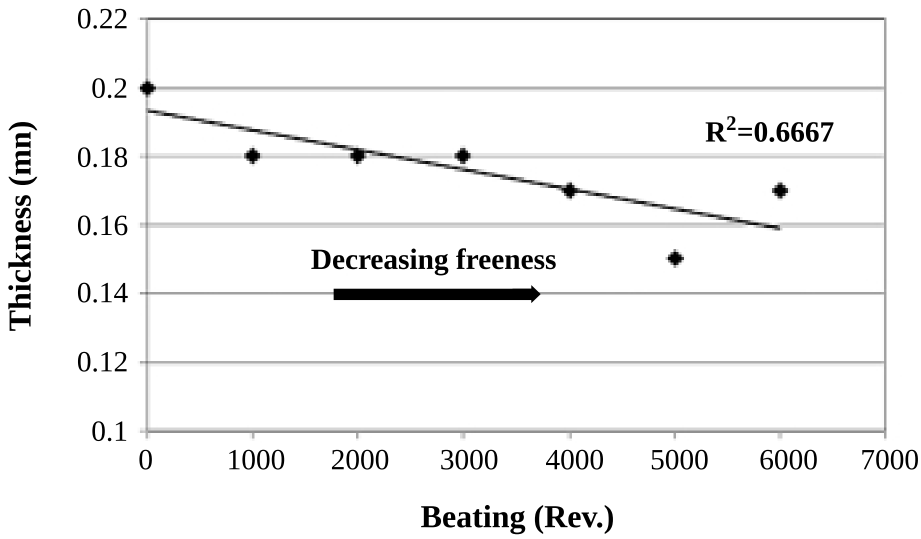

Figure 4. The relationship between thickness and beating levels of unbleached sweet bamboo kraft pulp.

Density and Bulk

The relationships between density and bulk and beating level of unbleached sweet bamboo kraft pulp are shown in Figure 5 and 6. Both graphs demonstrate that when beating revolution continues to raise, then the density increases which is in contrast with bulk properties. Density of paper is usually a converse of bulk of paper. Hence, when bulk decreased, density should be increased. Fiber surface of unbeaten pulp isn't destroyed and break fiber to fibril (fine fiber). Thus, its fiber surface is more smoothness than beaten pulp. When unbeaten pulp forms a handsheet it is bulky and compare to beaten pulp that can form dense handsheet. The fibrillations of beaten fibers are increase fiber-to-fiber bonding and fine fibers plug holes in bonding area. Hence, paper having high density is the result from beating influence (Smook, 1997).

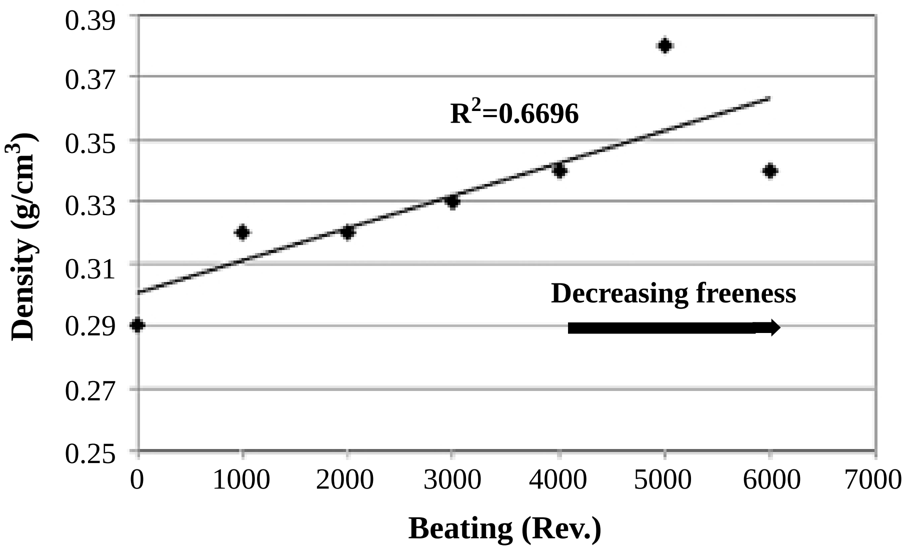

Figure 5. The relationship between density and beating levels of unbleached sweet bamboo kraft pulp.

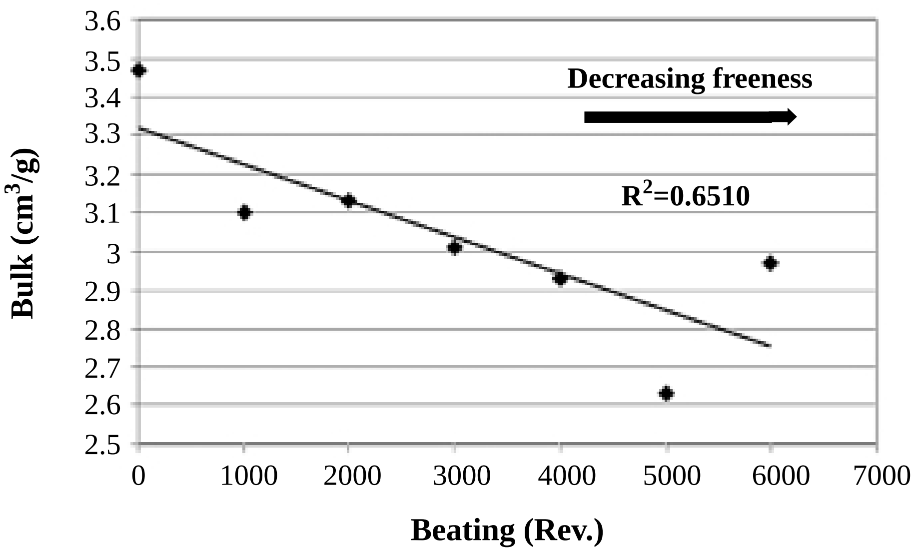

Figure 6. The relationship between bulk and beating levels of unbleached sweet bamboo kraft pulp.

Tensile Strength

The tensile indices of all unbleached sweet bamboo kraft pulps were 22.44–70.20 Nm/g (Table 3). Figure 7 shows the relationship between tensile index and freeness. It can be seen that the trend of tensile strength development after beating of kraft pulp was identical. When freeness decreased, resulting from increasing beating revolution, tensile index also increased until the maximum tensile index was reached and it was 70.20 Nm/g at 4000 beating revolution and 388 ml, CFS. Consequently, tensile index decreased if the pulps were continuously beaten for a longer period.

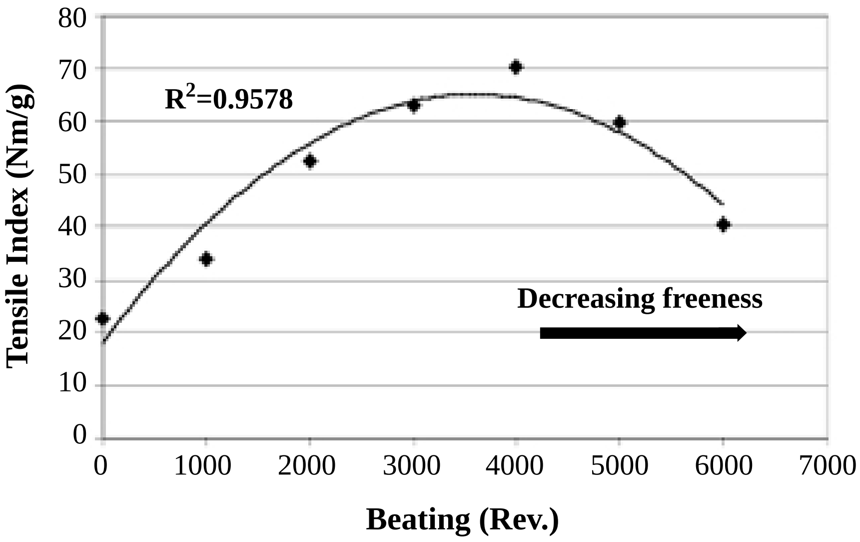

Figure 7. The relationship between tensile index and beating level of unbleached sweet bamboo kraft pulp.

Tear Strength

The range of tear index of all unbleached sweet bamboo pulp was 10.29–35.82 mNm^2/g (Table 3). Figure 8 indicates the trend of tear strength development against freeness of unbleached sweet bamboo kraft pulps which was almost similar to tensile strength. The development of unbleached sweet bamboo tear strength continued to increase when the beating levels were raised until over-beatability when it decreased together with the reduction of freeness. The highest tear strength was 35.82 mNm^2/g at 4000 beating rev. and freeness 388 ml, CSF. This is in contrast with the results obtained from unbleached Douglas fir pulp, beaten by PFI mill, which showed that tear strength continued to decrease when beating revolutions increased (Biermann, 1993).

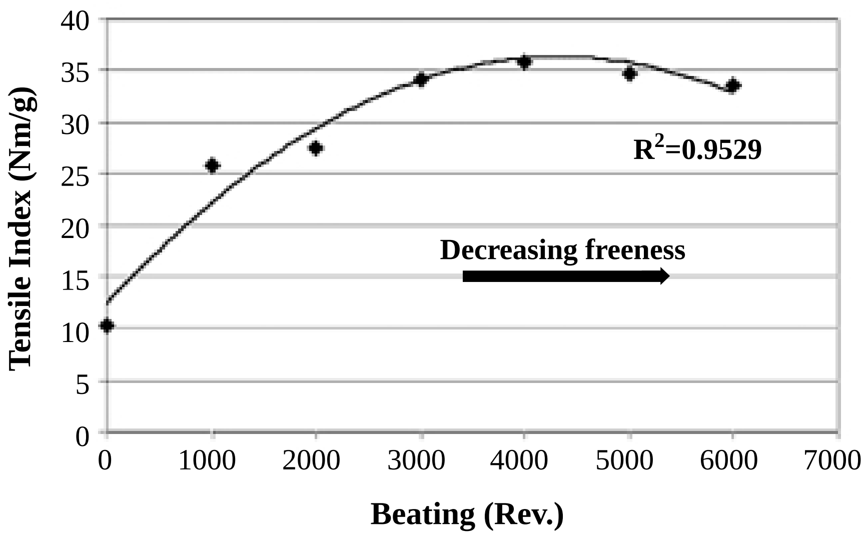

Figure 8. The relationship between tear index and beating level of unbleached sweet bamboo kraft pulp.

Tensile and Tear Strength Relationship

Figure 9 shows the relationship between tensile and tear strength of unbleached sweet bamboo kraft pulp. Generally, tensile and tear strength depends highly on fiber morphology such as fiber length, cell wall thickness and fiber strength. For instance, if fiber has long and thick cell wall, it could improve both strength after beating. Beating can make more fibrillation and fiber-to-fiber bonding than non-beating pulp (Smook, 1997). Kamthai (2003) illustrated fiber morphology of sweet bamboo to be long, with very thick cell wall and narrow lumen. Thus, it means its fiber morphology can produce paper which has high tensile and tear strength. From Figure 9 it can be seen that development of tensile-tear strength curve of pulps was similar. When beating revolution continued to raise, both tensile and tear strength were also increased.

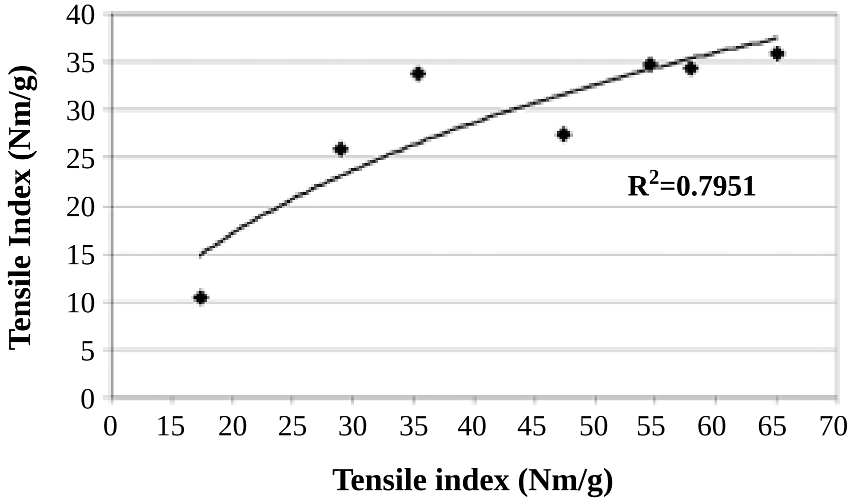

Figure 9. The relationship between tensile strength and tear strength of unbleached sweet bamboo kraft pulp.

Burst Strength and Folding Endurance

The burst index and folding endurance of unbleached sweet bamboo kraft pulp, when compared to other pulp properties, were similar. The curve of both properties continued to increase until at beating revolution of 5000 rev. (300 ml, CSF; freeness). At this beating level, the highest burst index and folding endurance were obtained which were 4.10 kPa.m2/g and about 429 r/c, respectively. Figures 10 and 11 present the relationship of burst index and folding endurance at different beating levels. The results of both properties depended on the beatability of unbleached sweet bamboo kraft pulp. When freeness value decreased, burst strength and folding endurance increased.

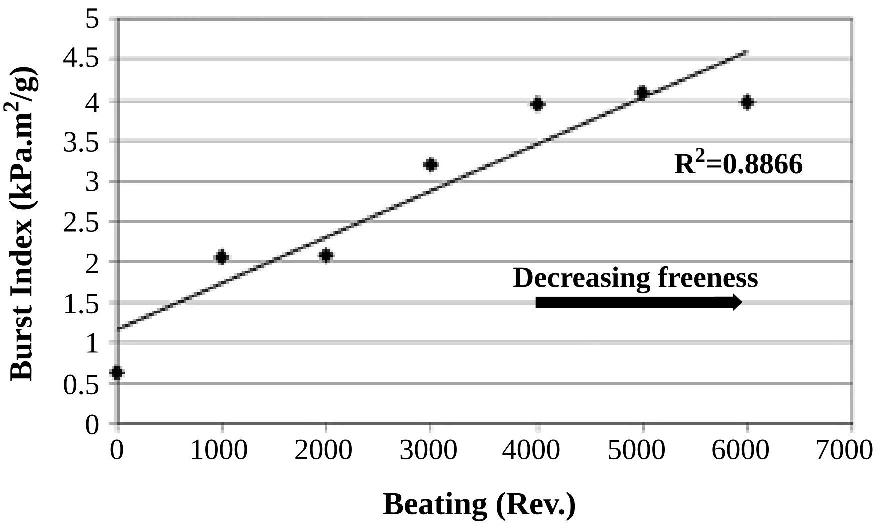

Figure 10. The relationship between burst index and beating level of unbleached sweet bamboo kraft pulp.

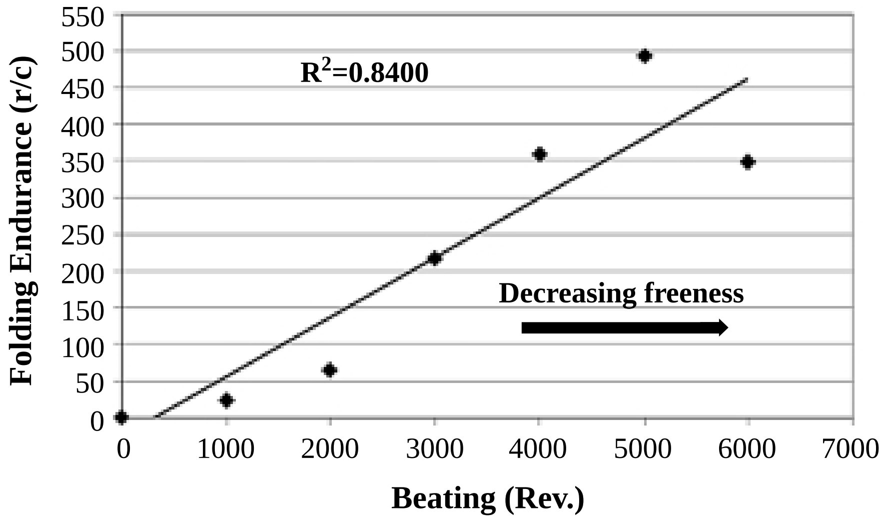

Figure 11. The relationship between folding endurance and beating level of unbleached sweet bamboo kraft pulp.

Optical properties as Brightness

Generally, all unbleached pulp has low brightness value but it depends on pulping processes and pulping condition that can reduce and remove lignin content in wood and non-wood fiber. For example, kraft pulping has important disadvantages: (1) high lignin content in pulp, (2) dark pulp color and (3) difficult to beach (Smook, 1997). All of the reasons referred to unbleached sweet bamboo kraft pulp indicated that it had low brightness as 20% ISO (Table 3). Bhargava (1987) reported the brightness of unbleached bamboo kraft pulp to be about 24% ISO. From this experiment, it was found that the beating revolution had slight effect on brightness of unbleached sweet bamboo kraft pulp.

CONCLUSION

Kraft pulping process from sweet bamboo seems to be feasible to produce high yield pulp at low kappa number. When the active alkaline charge was increased about 2%, the screened yield and kappa number was also decreased by 2%.

The investigations of unbleached sweet bamboo kraft pulp properties were indicated by beating revolution. The results can be concluded that beating levels affected mainly all pulp strength and slightly in case of optical properties as brightness. The pulp properties of unbleached sweet bamboo had high strength such as tensile, tear and burst strength and folding endurance.

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