Chiang Mai J. Sci. 2007; 34(1) : 97-107
www.science.cmu.ac.th/journal-science/josci.html
Contributed Paper

Comparisons of AS-AQ Pulping of Sweet Bamboo (*Dendrocalamus asper* Backer) and Pulping by Conventional Kraft Process

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Received: 24 April 2006
Accepted: 30 December 2006.

ABSTRACT

Sweet bamboo chips were pulped by using alkaline sulfite pulping (AS), alkaline sulfite pulping with anthraquinone (AS-AQ) and conventional kraft pulping was used as reference. In the case of AS pulping was modified by adding 0.1 % anthraquinone (AQ) in to AS cooking liquor for compared delignification rate, screened yield and unbleached pulp properties. Considering the AS-AQ pulping process found that the addition of 0.1% AQ can raised the delignification rate which indicated by kappa number and pulping yield. The AS and AS-AQ screened yields were approximately about 10% higher than kraft screened yield but AS-AQ and kraft kappa numbers were averaged about 18 points lower than AS kappa number. The AS and AS-AQ kappa numbers presented AS pulp had higher kappa number than AS-AQ pulped about 19 points. At the similar kappa number of about 12.5 points, kraft pulping had lower pulping yield than AS-AQ pulp yield about 9.2%. They were 46.3% and 55.6% respectively. After that unbleached kraft and AS-AQ pulps were refined by PFI mill for pulp properties testing. The result indicated unbleached AS-AQ pulp and it required higher energy consumption for beating than unbleached kraft pulp about 1000 revs. The mechanical strength properties of unbleached AS-AQ pulp were lower than those of unbleached kraft pulp. The highest mechanical strength properties of unbleached kraft pulp such as tensile, tear, burst strength and folding endurance, which were 70.2 Nm/g, 35.8 mN.m^2/g, 4.1 kPa.m^2/g and 492, respectively.

Keywords: *Dendrocalamus asper* Backer, alkaline-sulfite pulping, alkaline-sulfite pulping with anthraquinone, kraft pulping, kappa number, delignification, pulped yield.

1. INTRODUCTION

Wood fiber based pulp industry in Thailand relied on the use of *Eucalyptus camaldulensis* and it was cloned as short fiber raw material for papermaking processes. In papermaking, some kind of high strength paper should be added to long fiber for strength increment. Nowadays the lack of long fiber support in Thailand's pulp and paper industries should be considered and it is 100% imported, mainly from Canada, Chile, USA and South Africa [1]. The value of virgin pulp and waste paper imported from aboard which were 378.1 million US$ in 2004 [2]. Thus the new long fiber resource for pulp and paper production is pointed toward non-wood plant fiber such as bamboo.

Sweet bamboo is the one of bamboo species which can be more utilized in Thailand. Due to its fiber morphology was indicated that it was long fiber and very thick cell wall. Kamthai reported the approximate fiber dimensions of sweet bamboo such as: length 3.11 mm, fiber width 18.03 mm, lumen width 4.35 mm and cell wall thickness 9.68 mm and the important chemical compositions were holocellulose 76.33%, lignin 28.70%, and ash content 1.46% [3]. The sweet bamboo fiber morphology and chemical contents can predict its pulp property has high strength like as softwood fiber.

The most popular pulping process in the world is kraft pulping process because of its excellent pulp strength and its easy recovery of chemicals. But mainly disadvantages of this pulping process are low pulped yield and it has unpleasant smell by poisonous gases such as hydrogen sulfide, methyl mercaptant, dimethyl sulfide and dimethyl disulfide. In order to eliminate gases emission and increase pulped yield from kraft pulping, the application of new pulping processes was modified by anthraquinone (AQ) as alkaline sulfite pulping process with anthraquinone (AS-AQ). AQ has maximum effect on degradation of lignin and stabilization of carbohydrate in pulping process [4]. The addition of AQ in cooking liquor can accelerate delignification rate, reduce kappa number and protect cellulose degradation. Thus the utilization of AQ in pulping process should be investigated in sweet bamboo pulping.

The objectives of this work was: (1) to optimize pulping processes with high pulping yield and give suitable kappa number and (2) to evaluate properties of obtained pulp from unbleached sweet bamboo pulps.

2. MATERIALS AND METHODS

2.1 Raw Material Preparation

In this study, 3 – year old sweet from bamboo plantation in Prachinburi province was utilized. The bamboo culms were selected and cut at 0.30 m above ground. They were cut for pulping process. For pulping experiment, sweet bamboo culms were chipped and screened in 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 chip was determined using TAPPI T258 om-02. Then sweet bamboo chips were dried at atmosphere condition and then packed in plastic bag around 700 g, oven-dry weight.

2.2 Pulping Processes

The experiment, alkaline sulfite pulping (AS), alkaline sulfite pulping with anthraquinone (AS-AQ) and kraft pulping processes were studied. The white liquor used in AS cooking was prepare from fresh sodium sulfite (Na_2SO_3), sodium hydroxide (NaOH) and only AS-AQ cooking was added 0.1% AQ in AS white liquor. For kraft pulping process commercial sodium hydroxide and sodium sulfide (Na_2S) were used and analyzed according to SCAN-N 2:88. The 700 g oven-dry weight chips were cooked in a 7-liter rotating digester by cooking conditions that were listed in Table 1.

After pulping, brown stock was washed with excess tap water and followed by mechanical disintegrator disintegrated pulp. Then cooked pulp was screened through 0.15 mm screen plate (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 T278 sp-99). The pulp yields and reject content, as percentage on an oven dry weight, were calculated.

Table 1. Cooking conditions of AS, AS-AQ and Kraft pulping.

Cooking conditions	AS	AS-AQ	Kraft
Chemical charge (%)*	25 - 30	25 - 30	-
$Na_2SO_3/NaOH$	70 : 30	70 : 30	-
Active alkaline (%)*	-	-	14 - 20
Sulfidity	-	-	30
AQ (%)*	-	0.1	-
Liquor to wood ration	4 : 1	4 : 1	4 : 1
Time to max (min)	90	90	60
Time at max (min)	90	90	90
Temperature (°C)	170	170	170

* Base on oven-dry weight of sweet bamboo chips

2.3 Testing of Papermaking Properties

The unbleached sweet bamboo pulp was beaten in PFI mill (pulp beating devices) 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 hand-sheet for testing of papermaking properties was formed according to TAPPI T205 sp-02. The hand sheet of each beating condition was measured 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 T403 om-97) and folding endurance (TAPPI T511 om-02).

3. RESULTS AND DISCUSSION

3.1 Pulping Processes

All cooking results from AS AS-AQ and kraft pulping processes are presented in Table 2. In this part the effect of pulping condition on pulp yield and kappa number in each pulping process was studied and

Table 2. The results of sweet bamboo AS, AS-AQ and kraft pulping.

Process	Condition	Pulping yield(%)	Kappa number
AS - pulping	A20 - 70:30 - 90 - 90 - 170 - 4:1	56.6	34.7
	A25 - 70:30 - 90 - 90 - 170 - 4:1	55.9	32.5
	A30 - 70:30 - 90 - 90 - 170 - 4:1	55.9	31.0
	A35 - 70:30 - 90 - 90 - 170 - 4:1	55.7	23.6
AS – AQ pulping	A20 - 70:30 - 90 - 90 - 170 - 4:1 + AQ 0.1%	53.8	13.7
	A25 - 70:30 - 90 - 90 - 170 - 4:1 + AQ 0.1%	55.6	12.5
	A30 - 70:30 - 90 - 90 - 170 - 4:1 + AQ 0.1%	56.7	11.4
	A35 - 70:30 - 90 - 90 - 170 - 4:1 + AQ 0.1%	56.3	9.6
Kraft pulping	S30 - A14 - 60 - 90 - 170 - 4:1	48.8	17.8
	S30 - A16 - 60 - 90 - 170 - 4:1	46.3	12.5
	S30 - A18 - 60 - 90 - 170 - 4:1	43.3	10.5
	S30 - A20 - 60 - 90 - 170 - 4:1	42.7	8.4

compared between all pulping processes. Consequently, active alkaline increased that it had strongly affected only unbleached kraft pulp. It continued to decrease and compared to unbleached AS and AS-AQ pulps, which slightly reduced. Figure 1 shows the relationship between kappa number and screened yield of all unbleached sweet bamboo pulps. The pulping results indicated unbleached AS and AS-AQ pulped yields were 55.7 – 56.6% and 53.8–56.7%, respectively. They were approximately about 10% higher than unbleached kraft pulped yield. It was 42.66–48.83%.

In the pulping experiment, the delignification rate was observed by the kappa number and it could be presented by the amount of lignin content which remained in unbleached sweet bamboo pulp after cooking. For instance, AS kappa number (34.7-23.6 points) was higher than AS-AQ and kraft kappa number. They were 13.7-9.6 and 17.8-8.4 points, respectively. The investigation found that the addition of 0.1% AQ in AS cooking liquor affected the delignification rate of AS pulping process which was presented by kappa number decreasing. AQ could be reduced AS kappa number and it was approximately reduced 18 points. Thus the reduction of kappa number in sweet bamboo pulping referred to AS-AQ pulping was more the delignification rate than AS-pulping. The delignification rates of pulping processes were ranked as following: kraft-AQ > kraft e" AS-AQ > NS-AQ [5]. The AS-AQ kappa number was less than kraft kappa number and it was about 0.50%. At similar kappa number of both pulping process about 12.5 points; AS-AQ pulped yield had higher than kraft pulped yielded about 9.3

The comparison of modified pulping by AQ addition in AS cooking liquor and kraft pulping process indicated AS and AS-AQ pulped yield higher than kraft pulped yield. The pulping condition was adjusted by added AQ that elucidated the AQ was work as a promoter to stabilized carbohydrate and accelerated lignin in pulping. After that lignin was removed and affected kappa number reduction. However the effect of AQ in pulping process on screened yield had less influenced. The investigation presented AS and AS-AQ screened yield was above 50%. The addition of AQ in cooking liquor, Ingruber Miller and Gounder mentioned that AQ in sulfite cooking liquor could be raise the rate of delignification rate and protected cellulose degradation [4,6]. Brain reported the adjusting pulping conditions by AQ addition, the pulping yield advantage could be traded for greater reduction in kappa number or conversely a smaller kappa number reduction with greater pulping yield increased [7].

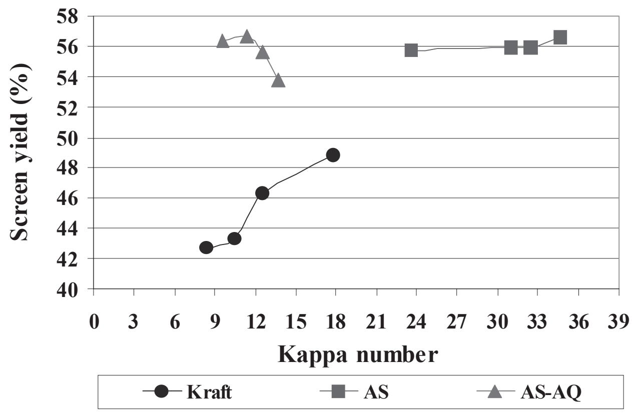

Figure 1. The relationship between kappa number and screened yield of AS, AS-AQ and kraft pulping.

Generally the bamboo pulping processes such as kraft pulping had 46 – 47%, screened yield and soda pulping had 44 – 45%, screened yield [8]. Sadawarte *et al* indicated bamboo kraft cooking result at 16% active alkaline and 20% sulfidity had pulped yield, 43.7% and 37.6 kappa number [9]. The 1-, 2- and 3- year old tropical bamboo (*Gigantochloa scortechinii*) was pulped by 16 - 18% NaOH, 170 ^{o}C and 3.5 hrs. Its screened yield and kappa number varied from 46 – 50% and 28 to 62, respectively [10]. Hong Man used Vietnam mixed bamboos such as 30% *Neohouzeaua Dullooa*, 30% *Dendrocalamus Membranaseus* Munro and 40% *Bambusa Procera* Acher in Soda – 0.1%AQ pulping. Her experiment revealed the screened yield and kappa number of Vietnam mixed bamboos were about 51.2% and 18.27, respectively [11]. Considering sweet bamboo as raw material for pulping, it could be pulped at high screened yield and low kappa number especially in AS-AQ pulping process. For example at the lowest kappa number (9.6), sweet bamboo AS-AQ pulped yield was 56.3%. Thus unbleached AS-AQ pulp was continued to evaluate pulp properties and compared with unbleached kraft pulp, which was used as reference at similar kappa number, 12.5.

3.2 Unbleached Pulp Properties

The pulp properties of unbleached sweet bamboo AS-AQ and kraft pulps are presented in Table 3. The result illustrates the effect of pulping processes on pulp properties and evaluated the beatability of both pulps by PFI mills. Figure 2 illustrates the relationship between freeness and beating level of unbleached sweet bamboo AS-AQ and kraft pulps. The drainability of both pulps continued to decrease when beating revel increased. The freeness value of unbleached sweet bamboo AS-AQ and kraft were reduced from 750 to 240 and 743 – 212 ml, CSF at different beating revolution; 0 – 7000 and 0 – 6000 revs., respectively.

Table 3. Physical and optical properties of unbleached sweet bamboo AS-AQ and kraft handsheet.

Pulp	Beating Revs. PFI mill	Freeness (ml,CSF)	Tensile Index (Nm/g)	Tear Index (mN.m^2/g)	Burst Index (kPa.m^2/g)	Folds	Brightness %ISO
Sweet bamboo AS - AQ	0	750	20.76	9.36	0.18	3	26.62
	1000	700	30.28	25.01	2.18	29	25.57
	2000	609	44.66	26.92	2.52	75	25.89
	3000	573	51.71	27.50	2.80	158	25.42
	4000	455	60.10	27.87	3.10	269	25.02
	5000	335	54.34	24.52	3.34	371	25.28
	6000	273	37.95	22.29	3.25	381	25.41
	7000	240	36.12	21.92	3.21	405	25.21
Sweet bamboo kraft	0	743	22.44	10.29	0.62	0	20.98
	1000	670	33.96	25.76	2.05	24	19.87
	2000	582	52.49	27.44	2.09	66	20.00
	3000	488	63.01	34.20	3.19	217	19.67
	4000	388	70.20	35.82	3.96	358	19.63
	5000	300	59.68	34.64	4.10	492	19.43
	6000	212	40.41	33.60	3.98	349	20.43

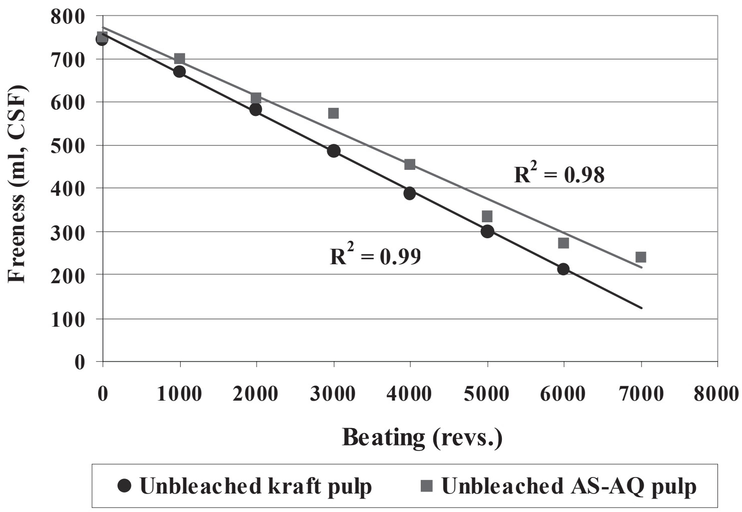

Figure 2. The relationship between freeness and beating level of unbleached sweet bamboo AS-AQ and kraft pulps.

The unbleached sweet bamboo pulp properties were importantly to evaluate the beatability of both unbleached pulps and it affected the strength of sweet bamboo paper. Biermann reported that the paper strength properties continued to rise by beating process which caused to make more fiber-to-fiber bonding [12]. Unbleached sweet bamboo pulps were used to form the handsheet with a grammage of 60 g/m^2 for pulp properties study. The results of unbleached sweet bamboo pulp properties presented its pulp properties were similarly wood pulps. They gave good strength properties especially tear strength and folding endurance probably because of the sweet bamboo fiber characteristic had long fiber and very thick cell wall. As seen in Table 3, all unbleached sweet bamboo kraft pulp had higher strength than unbleached sweet bamboo AS-AQ pulp. Miller and Gounder (1997) reported the strength comparison of mixed hardwood kraft and AS-AQ pulp presented kraft pulp had higher strength than AS-AQ pulp [6]. For beating energy requirement, the unbleached sweet bamboo AS-AQ pulp was slightly harder and more energy requirement to beat than unbleached sweet bamboo kraft pulp.

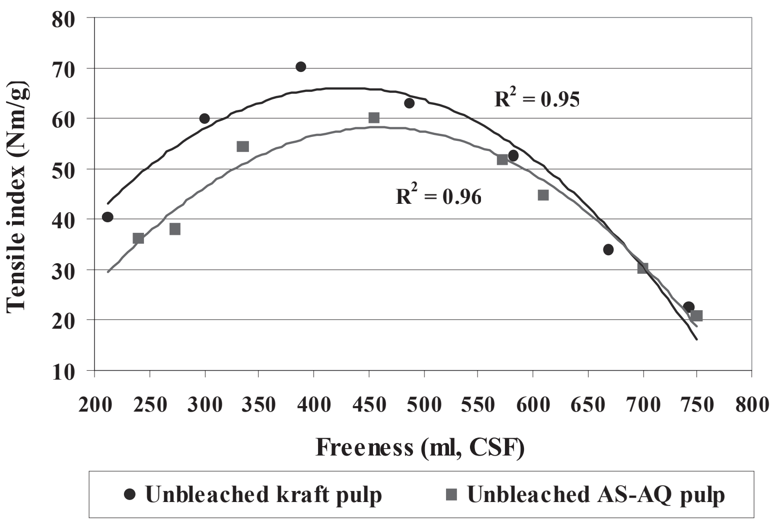

Figure 3. The relationship between tensile index and freeness of unbleached sweet bamboo AS-AQ and kraft pulps.

3.2.1 Tensile Strength

The tensile index of all unbleached sweet bamboo AS-AQ and kraft pulp were 20.76 – 60.10 and 22.44 – 70.20 Nm/g, respectively. Figure 3 demonstrates the relationship between tensile index and freeness of unbleached sweet bamboo pulps. It shows the trend of tensile strength development continues to increase and drop until the maximum tensile index occur. The highest tensile strength of unbleached sweet bamboo AS-AQ and kraft pulps indicated at 4000 revs. beating revolution and their freeness values were 455 and 388 ml, CSF; respectively. They were 60.10 and 70.20 Nm/g, respectively.

The fiber dimensions had strongly affected the principle of paper properties such as tensile and tear strength. Kauppinen reported that higher fiber length also gave better paper strength who indicated kraft wood fiber length about 1.0 mm had lower tensile index than 1.6 mm, fiber length [13]. Generally accepted strength theories started that fibers were stretched across the rupture zone and determines the tensile strength of paper and were among the most important factor for tear strength. The sweet bamboo morphology was relatively long fiber like as wood fiber. Thus tensile strength was high when sweet bamboo tensile strength compared with other bamboo species found that the tensile strengths of 3 years old tropical bamboo *Gigantochloa scortechinii*) soda pulp was 32 – 74 Nm/g at 0 – 10,000 revs [10].

3.2.2 Tear Strength

Tensile index was raised after beating tear index was increase as well and this property trended to decrease at high beating level when maximum tear index occurred. The range of tear index of unbleached sweet bamboo AS-AQ and kraft pulps were 9.38 – 27.87 and 10.29 -35.82 mN.m^2/g, respectively and illustrated in the figure 4. It presents the relationship between tear index and freeness of both unbleached bamboo pulps. The highest tensile index of unbleached sweet bamboo AS-AQ and kraft pulps were observed at 4000 revs, but theirs free were 455 and 388 ml CSF.

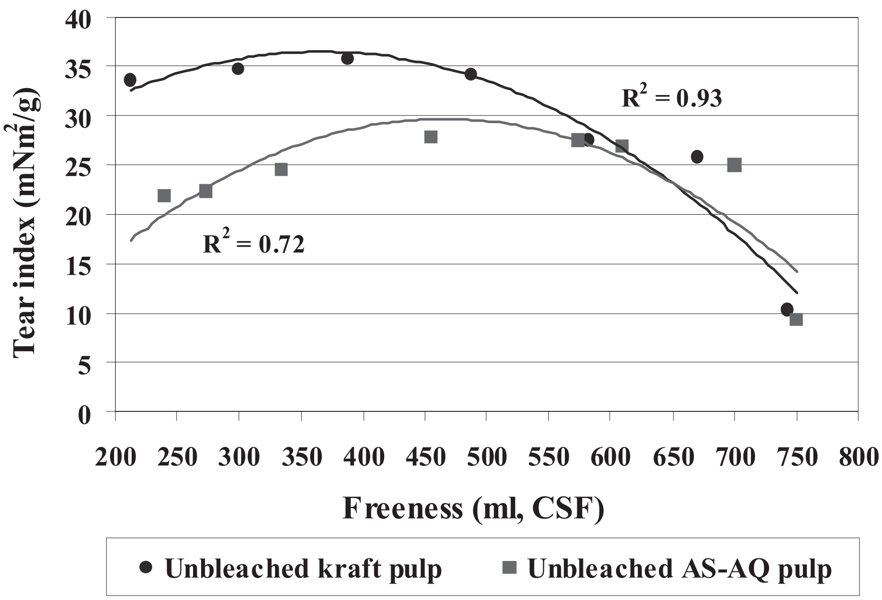

Figure 4. The relationship between tear index and freeness of unbleached sweet bamboo AS-AQ and kraft pulps.

The comparison of unbleached non-wood tear indexes such as banana and kenaf were investigated by Hart [14]. His research demonstrated tear index of both non wood pulps were 5 and 27 mN.m^2/g at 0 rev., respectively and it was lower than unbleached sweet bamboo tear indexes at unbeaten level. Yusoff, *et al.* (1992) demonstrated the tear strength of 3 years old tropical bamboo *Gigantochloa scortechinii*) soda pulp was 13.2 – 25.2 mNm^2/g at 0 -10,000 revs. [10]. Considering the tear resistance of unbleached aspen (*Populus Tremuloides*) pulp found that unbleached AS-AQ pulp had less tear index than kraft pulp and unbleached AS-AQ pulp was slightly harder to beat than kraft pulp[15]. Lab report the tear indexes of unbleached kraft hardwood pulp such as *Eucalyptus Camaldulensis* and *Acacia Auriculiformis* were 7.14 and 6.79 mNm^2/g, respectively [16]. Thus the experiment presented unbleached sweet bamboo pulp had had higher tear index than unbleached hardwood pulp.

3.2.3 Tear and Tensile Relationship

The tear and tensile relationship of unbleached sweet bamboo AS-AQ and kraft pulp snowed in figure 5. The relationship of both strengths had similarly trend to decrease when both unbleached sweet bamboo pulps were beaten at high beating levels. The results indicated the tensile and tear index of unbleached sweet bamboo pulps had the highest value at 4000 revs and 400 – 500 ml CSF, freeness value. Hart revealed the addition of AQ in non-wood kraft and soda pulp could be increased the tensile index and improved tear index also [14]. At similar beating revolution unbleached sweet bamboo kraft pulp had higher tensile and tear strength than unbleached sweet bamboo AS-AQ pulp. Smook reported that the kraft pulping process produced highest strength pulp [17].

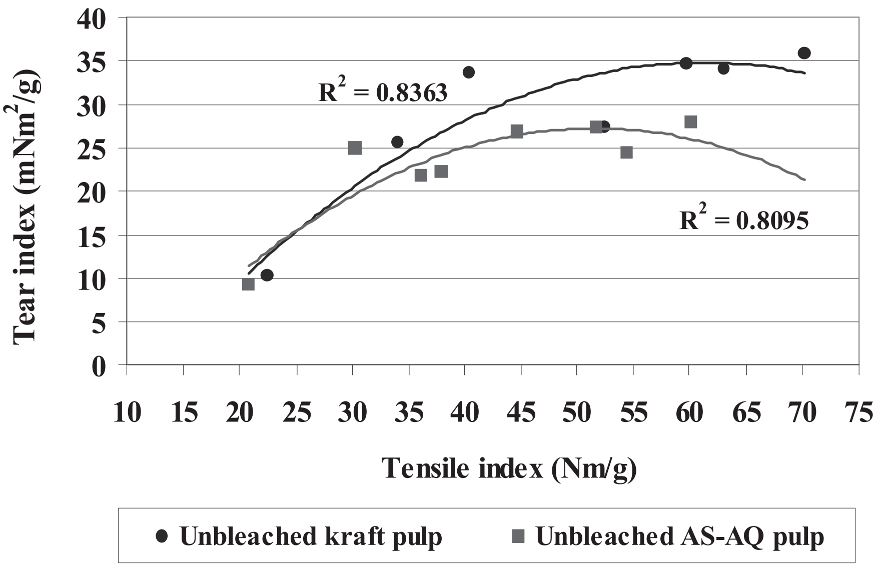

Figure 5. The relationship between tear and tensile strength of unbleached sweet bamboo AS-AQ and kraft pulps.

3.2.4 Burst Strength and Folding Endurance

The burst index and folding endurance of unbleached sweet bamboo AS-AQ and kraft pulp were similar and they are presented in figure 6 and 7. The burst strength curve of both sweet bamboo pulps had maximum strength at 5000 revs and freeness value was about 200 - 300 ml, CSF. At this beating level the highest burst index and folding endurance of kraft pulps was observed. They were 4.10

kPa.m^2/g and 492. Not only burst strength continued to increase at high beating revolution but also folding endurance of unbleached sweet bamboo AS-AQ and kraft pulps was raised. The best burst strength and folding endurance of AS-AQ pulps were indicated at 5000 revs, 335 ml, CSF and 7000 revs, 240 ml, CSF, respectively. They were 3.34 kPa.m^2/g and 405.

In case of burst strength and folding endurance of both unbleached sweet bamboo were related refining effect and fiber morphology. Particularly burst index could be evaluated by beating level and folding endurance depended on fiber length. At 7000 revs, beating level and freeness value about 430 ml, CSF presented the burst strength and folding endurance of 3 years old tropical bamboo (*Gigantochloa scortechinii*) soda pulp were 4.5 – 4.7 kPa.m^2/g and 376 – 558 ,respectively [10]. Sadawarte revealed the highest burst index of unbleached bamboo kraft pulp was occurred at 3500 revs. It was 5 kPa.m^2/g [9]. Atchison reported the folding endurance of unbleached short non-wood fiber kraft pulps such as reeds (1.0-1.8 mm) and bagasses (1.0-1.5 mm) were 350 and 400 at 300 ml CSF, respectively [18].

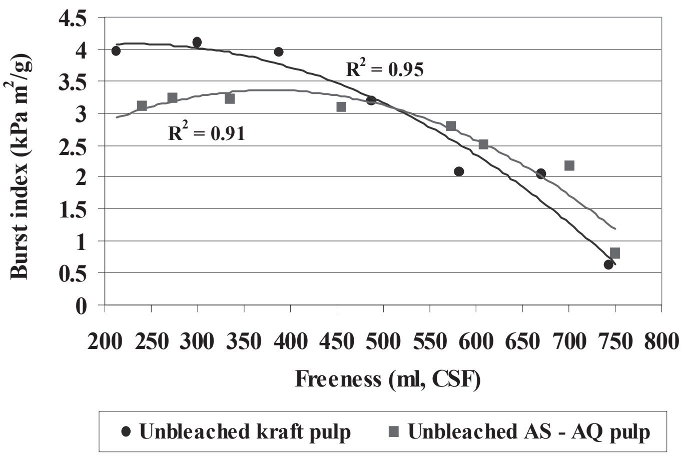

Figure 6. The relationship between burst index and freeness of unbleached sweet bamboo AS-AQ and kraft pulps.

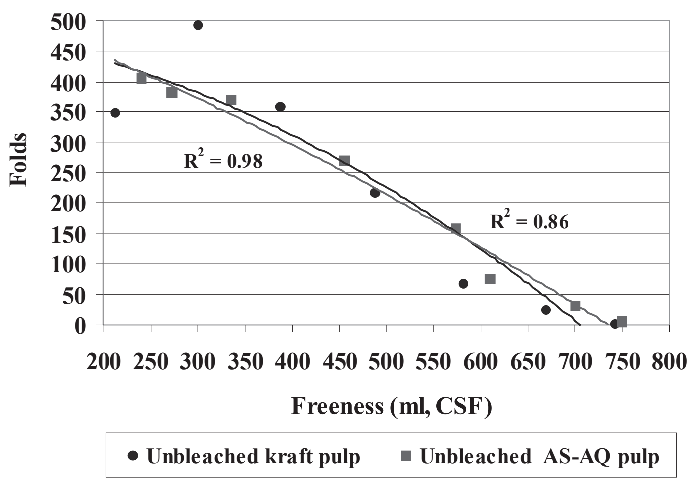

Figure 7. The relationship between folding endurance and freeness of unbleached sweet bamboo AS-AQ and kraft pulps.

3.3.4 Optical property

The result of brightness values were indicated by influence of pulping process had significantly affected optical properties. Due to the 0.1% AQ addition in AS pulping had an advantage such as higher brightness and easier to bleach and in contrast to kraft pulping which had lower brightness and more difficult to bleached [12,17]. At similar kappa number, 12.5 point unbleached sweet bamboo kraft pulp had lower brightness (19.43 – 20.98 %ISO) value than unbleached AS-AQ pulp (25.02 – 26.62%ISO) about 5% ISO. For the development of brightness values after both unbleached pulps were refined and it found that beating process had been slightly influenced.

4. Conclusions

The non-wood material; sweet bamboo can pulped by different pulping processes. The results of this experiment present the modification of AS pulping by 0.1% AQ adding in cooking liquor is accelerated lignin degradation, decreased Kappa number and maintained high pulped yield. Sweet bamboo AS and AS-AQ screened yield are approximately about 10% higher than kraft screened yield. The addition of AQ in AS-pulping can reduce Kappa number by about 19 points and AS-AQ screen yield is slightly decreased. At the similar kappa number about 12.5 point, kraft pulping has lower pulped yield than AS-AQ pulp yield about 9.25%.

The evaluation of unbleached strength and optical properties present all of those unbleached sweet bamboo kraft pulps has higher than AS-AQ pulps at equal kappa number. At 4000 and 5000 revs., the highest mechanical strength properties of tensile, tear, burst strength and folding endurance of unbleached kraft pulp are 70.20 Nm/g, 35.82 mN.m^2/g, 4.10 kPa.m^2/g and 492 , respectively. The beatability of both unbleached sweet bamboo pulps are illustrated AS-AQ pulp had more energy requirement for refining than kraft pulp. Surprisingly sweet bamboo pulps has high tensile and burst resistances like as wood pulps and particularly the tear strength and folding endurance is much higher than in wood pulps.

Acknowledgements

The author would like to thank Dr. Pratuang Puthson for recommendation, Asia Pacific Association of Forestry Research Institutions (APAFRI-TREE LINK project), the TRF/BIOTEC Special Program for Biodiversity Research and Training grant BRT T_644002 for finance support and also to Pulp and Paper Technology, Department of Forest Products, Faculty of Forestry, Kasetsart University, Kasetsart Agriculture and Agro-Industrial Product Improvement Institute (KAPI) and Department Packaging Technology, Faculty of Agro-Industry, Chiang Mai University for research equipment.

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