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EFFECT OF SODA-ANTHRAQUINONE PULPING CONDITIONS AND BEATING REVOLUTION ON THE MECHANICAL PROPERTIES OF PAPER MADE FROM *Gigantochloa scortechinii* (SEMANTAN BAMBOO)

(Kesan Faktor-Faktor Pemulpaan Soda-Antrakuinon dan Pemukulan Ke Atas Sifat-Sifat Mekanikal Kertas *Gigantochloa Scortechinii* (Buluh Semantan))

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Abstract

The effect of soda-AQ pulping conditions and beating revolution on the mechanical properties of paper made from Semantan bamboo (*Gigantochloa scortechinii*) was studied. The bamboo chips were pulped using MK digester pulping unit with 10 to 20% alkali charge and 150 to 170^oC cooking temperature. The screened yield varies from 38.7 to 48.4%, and each yield went through beating process at 1000 or 8000 beating revolutions. The bamboo pulp was then made into 60 g/m^2 laboratory scale papers and their mechanical properties were assessed conforming to TAPPI standards. The results revealed that tensile index, bursting index, tearing index and folding endurance ranged from 42.04 to 91.09 Nm/g, 2.68 to 7.10 kPa.m^2/g, 11.03 to 26.64 mN.m^2/g and 30 to 1127 double folds, respectively. The highest paper properties were found from pulping condition of 15% alkali charge and 150^oC cooking temperature based on the fibre bonding index, with tensile index at 87.71 Nm/g, bursting index at 6.94 kPa.m^2/g, tearing index at 12.72 mN.m^2/g and folding endurance at 613 double folds. Such findings indicate that comparable high strength mechanical properties of paper can be produced from Semantan bamboo pulp with more environmentally friendly pulping process compared to the kraft pulping process that had been used in bamboo pulping.

Keywords: soda-AQ pulping, Semantan bamboo, beating, paper mechanical properties

Abstrak

Kesan faktor-faktor pemulpaan soda-AQ dan pemukulan terhadap sifat-sifat mekanikal kertas buluh Semantan (*Gigantochloa scortechinii*) telah dikaji. Cip-cip buluh dimasak menggunakan unit penghadam MK dengan peratusan alkali 10 hingga 20% dan suhu pemulpaan pada 150 hingga 170^oC. Hasil penskrinan yang diperolehi adalah daripada 38.7 hingga 48.4%, dan selepas itu setiap hasil pulpa menjalani proses pemukulan pulpa pada 1000 atau 8000 revolusi pemukulan. Pembuatan kertas makmal 60 g/m^2 adalah berdasarkan standard TAPPI. Keputusan ujian mendapati indeks tensil, indeks pecahan, indeks koyakan dan ketahan lipatan berada dalam julat 42.04 to 91.09 Nm/g, 2.68 to 7.10 kPa.m^2/g, 11.03 to 26.64 mN.m^2/g dan 30 to 1127 kali lipatan, masing-masing. Berdasarkan indeks ikatan antara gentian, sifat kertas yang tertinggi adalah pada tahap pemasakan yang menggunakan alkali sebanyak 15% dan suhu pemasakan pada 150^oC, dengan indeks tensil 87.71 Nm/g, indeks pecahan 6.94 kPa.m^2/g, indeks koyakan 12.72 mN.m^2/g dan ketahanan lipatan sebanyak 613 kali lipatan. Penemuan ini membuktikan kekuatan mekanikal kertas yang setara boleh dihasilkan daripada pulpa buluh Semantan dengan proses pemulpaan yang lebih mesra alam berbanding proses pemulpaan kraft yang biasa digunakan dalam pemulpaan buluh.

Kata kunci: pemulpaan soda-AQ, buluh Semantan, pemukulan, sifat-sifat mekanikal kertas

Introduction

Bamboo is one of the most diverse groups of plant in the grass family which belongs to the family of *Gramineae* and sub-family of ***Bambusoidae***. This fast growing monocotyledon plant can be found in temperate, subtropical and tropical areas. There are 75 genera and 1250 species of bamboo in the world and in Asia alone there are 14 genera and 120 species [1]. Ironically, bamboo exists naturally in the forest while plantation bamboo needs shorter time (3 to 5 years) to be harvested compared to hardwood or softwood fibre sources [2].

Traditionally in Malaysia, bamboo usage is very versatile in the rural areas as supplementary materials in the construction of walls for village house, ceilings and scaffoldings. Even furniture and handicrafts also used bamboo as the raw material [3-4]. Bamboo is also been used commercially or on organized scale by several industries. Most of the industries use *G. scortechinii* for manufacturing poultry cages, shade blinds, barbeque sticks, vegetable baskets, incense sticks, tooth picks, chopsticks, skewers, and joss paper [5-6].

Currently, Malaysia packaging industry used recycled paper as the main raw material for the papermaking. The problem is recycled paper has limited recycling process as it can be recycled 5 to 7 times before the fibre become shorter, stiff and difficult to collapse during papermaking process [7]. The virgin pulp need to be added to maintain the fibre strength, but imported virgin pulp such as softwood long fibre is expensive and can contribute to the increasing of the production cost. Alternative raw material of virgin pulp is needed in contribution of enhancing the recycled paper strength.

In the paper making process, the beating process is mainly to increase fibre to fibre bonding in the paper. The beating level increases the surface area of pulp fibre and it is essential towards increasing the paper strength properties [8]. Biermann [9] presented that the action of beating or refining on pulp fibre causes fibrillation, thus exposure of cellulose fibrils subsequently increases the surface area of the fibre.

The aim of this paper is to study the suitability of Semantan bamboo for papermaking with more environmentally friendly pulping process i.e. soda-AQ pulping, compared to kraft pulping. In addition, this study also looks at the paper mechanical properties enhancement through beating process. The study also investigates the effects of alkali charge and pulping temperature on the paper mechanical properties.

Experimental

Soda-AQ pulping

The bamboo chips were pulped using Soda-Anthraquinone (AQ) pulping process with variables of 10 to 20% alkali charge and 150 to 170^{o}C cooking temperature as listed in Table 1. The fixed parameters for each batch of bamboo pulping were, 90 mins to reach pulping temperature, 90 mins at pulping temperature, 0.1% AQ, 1:4 bamboo to liquor ratio.

Table 1. Soda-AQ pulping variables

Treatment	**Alkali (%)**	**Temperature (^{o}C)**
1	**10**	150
2	**10**	160
3	**10**	170
4	**15**	150
5	**15**	160
6	**15**	170
7	**20**	150
8	**20**	160
9	**20**	170

Beating process

The beating process was conducted using the PFI beater at 1000 and 8000 beating revolutions. The beating revolution was chosen based on the previous study from 1000 to 24000 beating revolution [10]. It showed that after 8000 to 24000 beating revolution, there was no significant increasing of paper mechanical properties with the increasing of the beating revolution. That is the justification of this study for using 1000 beating as the basic beating process and 8000 as the optimum beating for achieving highest paper properties. Details of beating process conducted in this study are shown in Table 2 below.

Table 2. Description of Beating process

Treatment	Alkali (%)	Temperature (^{o}C)	Beating (revolution)
1	**10**	150	1000 & 8000
2	**10**	160	1000 & 8000
3	**10**	170	1000 & 8000
4	**15**	150	1000 & 8000
5	**15**	160	1000 & 8000
6	**15**	170	1000 & 8000
7	**20**	150	1000 & 8000
8	**20**	160	1000 & 8000
9	**20**	170	1000 & 8000

Papermaking and paper testing

The 60 g/m^2 laboratory papermaking process was based on the TAPPI standard T205 cm-88. After the papermaking process was completed, the paper was put into the conditioning room (temperature 23 ± 1^{o}C, relative humidity 50 ± 2%) for 24 h. Then they were cut accordingly (Figure 1) for specific paper testing. Mechanical testing such as tensile, bursting, tearing, folding and zero-span testing were done to examine the influence of alkali charge, cooking temperature and beating effect on the paper properties. Table 3 shows the TAPPI standards used in the paper testing process.

Table 3. TAPPI standards for paper mechanical testing

Mechanical testing	TAPPI standards
Tearing index	T414 om-88
Folding endurance	T511 om-88
Tensile index	T404 cm-92
Bursting index	T403 om-91
Zero-span	T231 cm-96

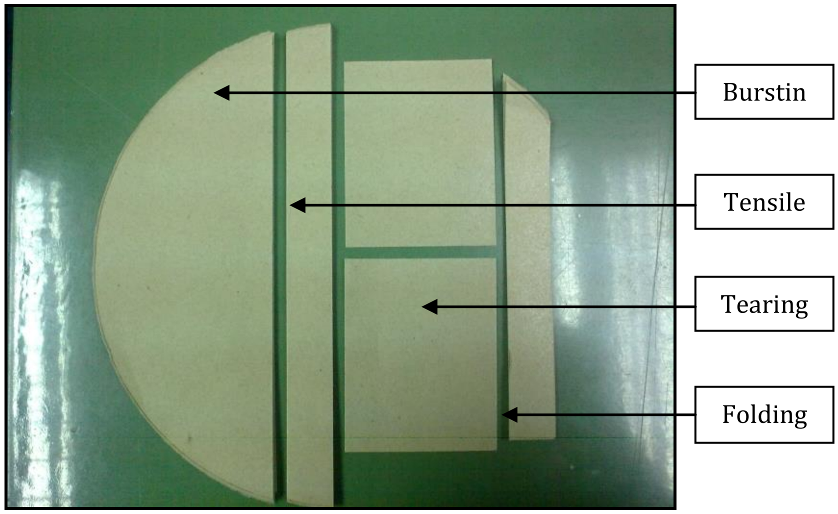

Figure 1. Paper segregation for specific testing

Results and Discussion

Soda-AQ pulping

Before the papermaking process, the pulp needed to go through a screening process. Cooked bamboochips were put through the screening machine to produce a screened yield. Only acceptable size of fibre can go through the screen plate and rejected or oversized fibre will be left on the screen plate. This process is crucial in papermaking manufacturing to ensure smooth and uniform paper texture.

Figure 2 shows the overall screened yield for soda-AQ pulping conducted in this study. As can be seen in the bar graph, there was a decreasing pattern on screened yield percentage with the increasing of the alkali charge percentage in all pulping temperature range. The highest screened yield was produced from the lowest alkali charge percentage (10%) and moderate pulping temperature (160^{o}C) i.e. treatment number 2 where by the screened yield is at 48.38%. This is good in terms of cost effeciency for commercial scale, as only small amount of chemicals and moderate energy power are needed for the pulp production, while the lowest screened yield was produced from the highest alkali charge (20%) and highest pulping temperature (170^{o}C) where only 38.70% screened yield was produced in treatment number 9 (Table 1). This might be due to the cellulose, hemicelluloses and lignin dissolved more in higher alkaline percentage and higher temperature, and thus decreasing the pulping yield.

Beating process and paper testing

Figure 3 shows the tearing index for all treatments which consist of 9 treatments for 1000 beating revolutions and also 9 treatments for 8000 beating revolutions. The tearing index slightly increased with the increasing of the alkali charge and pulping temperature as can be seen from the results in treatment 1 to 9, except for pulping conditions with 170^{o}C temperature and 20% alkaline percentage. This may due to at high temperature and active alkaline, more hemicellulose and cellulose chain were dissolved and thus produced shorter or weaker fibre. For tearing index, the 1000 beating revolutions gave higher results compared to 8000 beating revolution because the tearing index decreased with the increasing of the beating process made on the fibre. A slight beating process (1000 beating revolution) will make the fibre more flexible and can produced better bonding between fibres in the paper sheets and thus can enhance the tearing properties compared to unbeaten pulp. But, further beating process will make the fibre shorter and less bonding area between fibres can occurred, so less energy is needed to tear up the paper sheets and contribute to the decreasing of the tearing index with the increasing (8000 beating revolution) of the beating process.

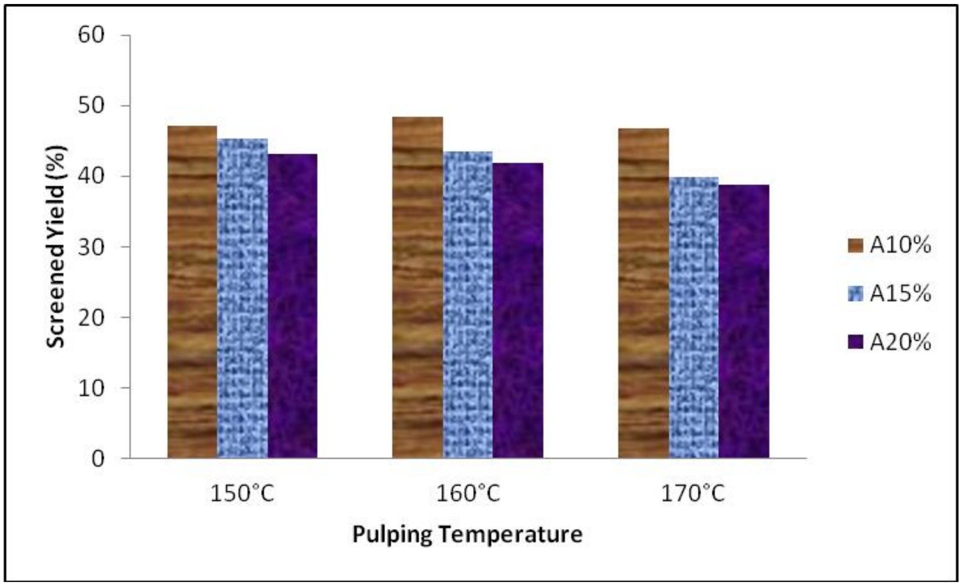

Figure 2. Soda-AQ pulping screened yield

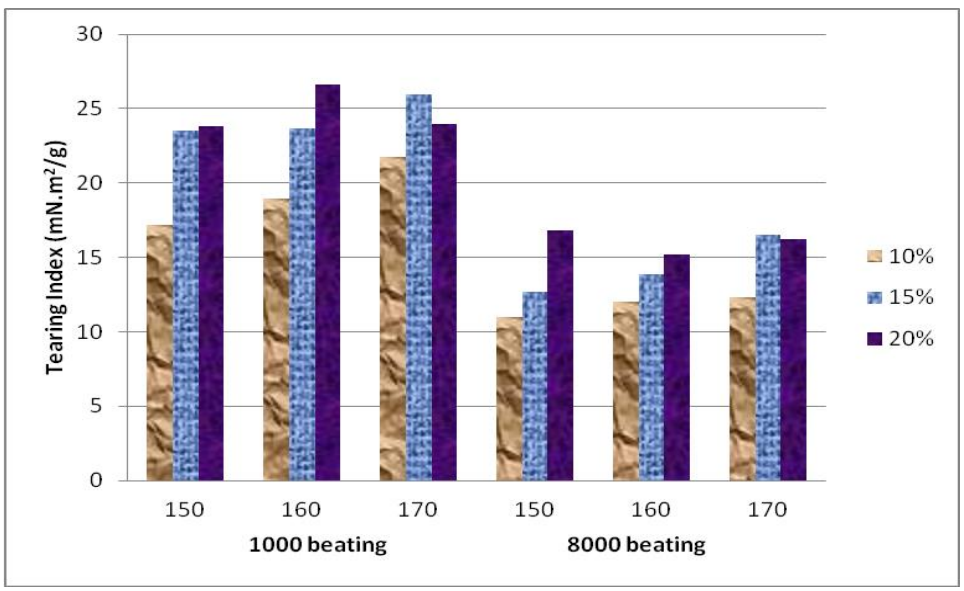

Figure 3. Tearing Index for 1000 and 8000 beating revolutions

The trend was contradicted with the tensile index whereby the trend shows that 8000 beating revolutions paper has higher tensile index compared to the 1000 beating revolutions paper as shown in Figure 4. Tensile index measures the paper resistance to being broken when the paper is stretch out from both sides. In terms of alkali charge and pulping temperature influence, the tensile index increased with the increasing of alkali charge and pulping temperature from 10 to 15% and 150 to 160°C, but slightly decreased when the alkali charge and pulping temperature kept increasing to 20% and 170°C. This also may due to degradation of hemicelluloses and cellulose in extreme high pulping conditions. Interestingly, as can be seen in Figure 4, highest tensile index occurs at every 15% of alkaline usage regardless the pulping temperature. It means that moderate alkaline percentage is sufficient enough to produce good paper strength. For both 8000 and 1000 beating revolutions, the highest tensile index was found in treatment number 5 (alkali charge 15% and pulping temperature 160°C), which produced tensile indexes 91.09 and 53.79 Nm/g respectively. For 8000 beating revolutions paper, the fibre bonding in the paper was closer and produced higher resistance to being broken and thus produced high tensile index compared to the 1000 beating revolutions paper.

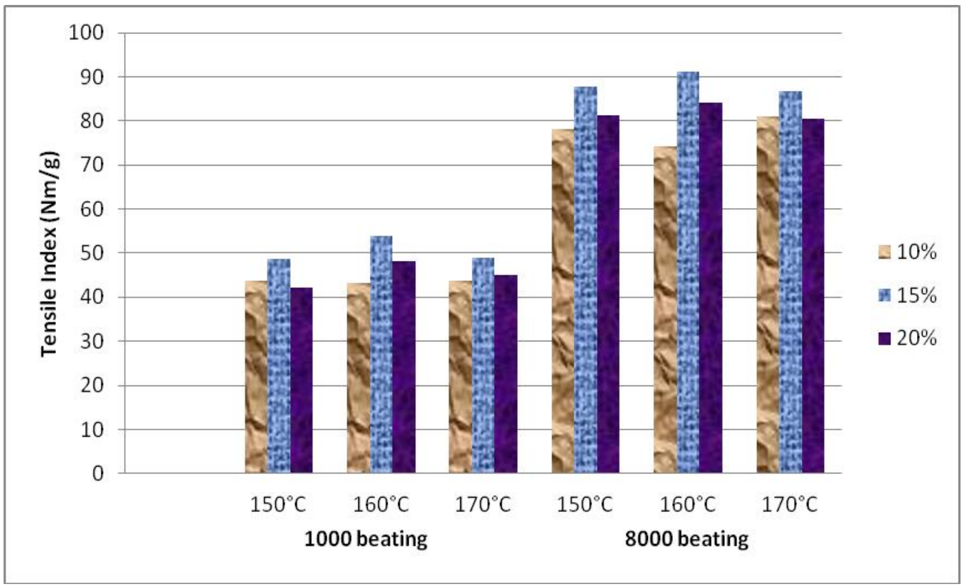

Figure 4. Tensile index for 1000 and 8000 beating revolution

The bursting indexes for 1000 and 8000 beating revolutions in Figure 5 also show the same trend as tensile index above. The bursting strength measures the paper resistance to being burst when hydraulic pressure was applied to the paper. The highest bursting strength was also found in treatment number 5 that produced 3.37 and 7.09 kPa.m^2/g for 1000 and 8000 beating revolutions respectively. Highest bursting index also occur at alkaline percentage of 15% regardless the pulping temperature. It shows that alkaline percentage has higher influence to the paper strength compared to pulping temperature. The 8000 beating revolution paper produced higher bursting strength compared to 1000 beating revolutions, due to higher inter-fibre bonding present in the 8000 beating revolutions paper. Thus the paper became more dense and more pressure was needed to break the inter-fibre bonding thus producing higher bursting index. Yusoff, *et al.* [11] reported that burst strength for 3 year old tropical bamboo *Gigantochloa scortechinii* soda pulp range from 4.5 to 4.7 kPa.m^2/g. Sadawarte *et al.* [12] revealed the highest burst index of unbleached bamboo kraft pulp occurring at 3500 revolutions, was 5 kPa.m^2/g.

Figure 6 shows the folding endurance for 1000 and 8000 beating revolutions papers from Semantan bamboo. It clearly shows that the 8000 beating revolution paper produced better folding endurance as compared to the 1000 beating revolutions paper. The folding endurance measures how many times the paper can be folded (double folds) with a 1g force being attached to it before the paper tears due to the folding action. For the 8000 beating revolutions paper, the fibre bonding in the paper was closer and the paper formation was better and could be folded many times before the paper tore compared to the 1000 beating revolutions. As in tearing, tensile and bursting index, the highest folding endurance was found in treatment number 5, which produced 68 and 1127 double folds for 1000 and 8000 beating revolutions respectively.

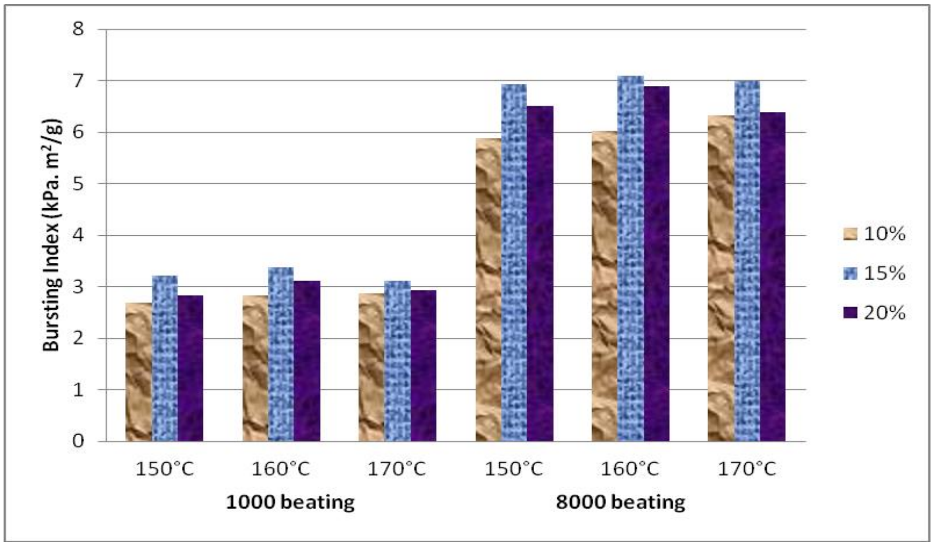

Figure 5. Bursting Index for 1000 and 8000 beating revolutions

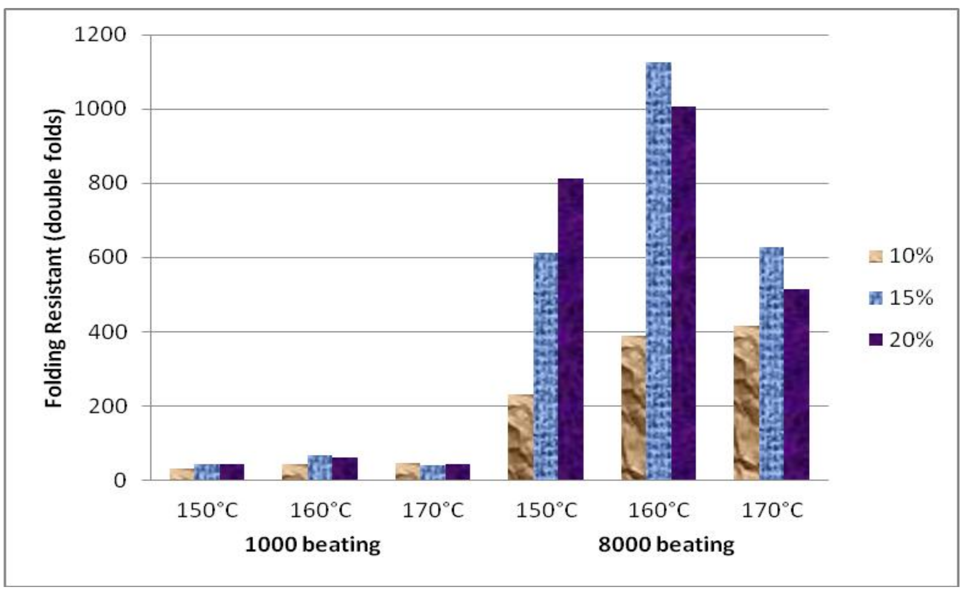

Figure 6. Folding endurance for 1000 and 8000 beating revolutions

Figure 7 shows the zero-span index for 1000 and 8000 beating revolutions paper. The zero-span strength determined the strength of individual, single fibre in the paper. The zero-span tensile test measures the tensile strength at the moment of tensile failure of fibres randomly oriented in a paper sheet. One important usage of zero-span tensile data is to determine the maximum strength of pulp fibres when beaten under idealized laboratory conditions. The alkali charge percentage and pulping temperature gave more influence to the paper individual fibre as the zero-span index increased with the increasing of alkali charge and pulping temperature, compared to the beating effect. At this time, treatment number 6 with 1000 beating revolutions gave the highest zero-span index which was 153.01 Nm/g.

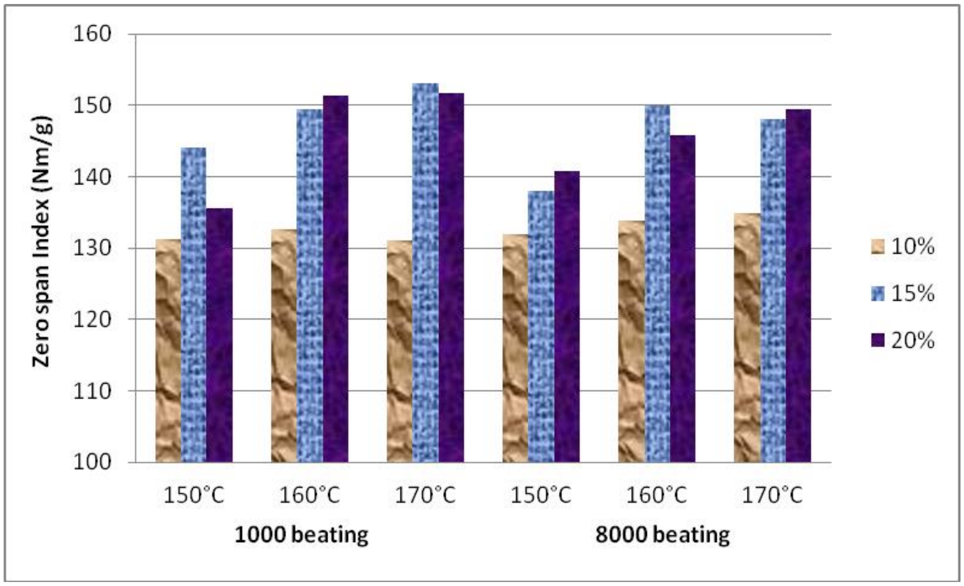

Figure 7. Zero-span Index for 1000 and 8000 beating revolutions

Figure 8 shows the fibre bonding index of the Semantan bamboo studied in this paper under the condition of 1000 and 8000 beating revolutions. The bonding index determination was based on Page's Simplified Equation, that showed the relationship between zero-span and tensile index, as stated in equation below:

$$B = \frac{8ZT}{8Z - 9T}$$

where B = bonding index, Nm/g
Z = zero-span index, Nm/g
T = tensile index, Nm/g

Although most of the paper mechanical testing results namely, tearing, tensile, bursting index and folding endurance tests showed that treatment number 5 (alkali charge 15% and pulping temperature 160^{o}C) had the highest paper properties based on the fibre bonding index, which consider the relationship between tensile index and zero-span index, it can be seen that the optimum paper mechanical properties was derived from treatment number 4, which involved alkali charge of 15% and pulping temperature of 150^{o}C.

Table 4 shows the analysis of variance for all paper mechanical properties discussed above. All the properties show significant and highly significant different between each treatment except for temperature factor for bursting index was not significant. It shows that alkaline percentage and pulping temperature have high influence in mechanical paper properties of Semantan bamboo.

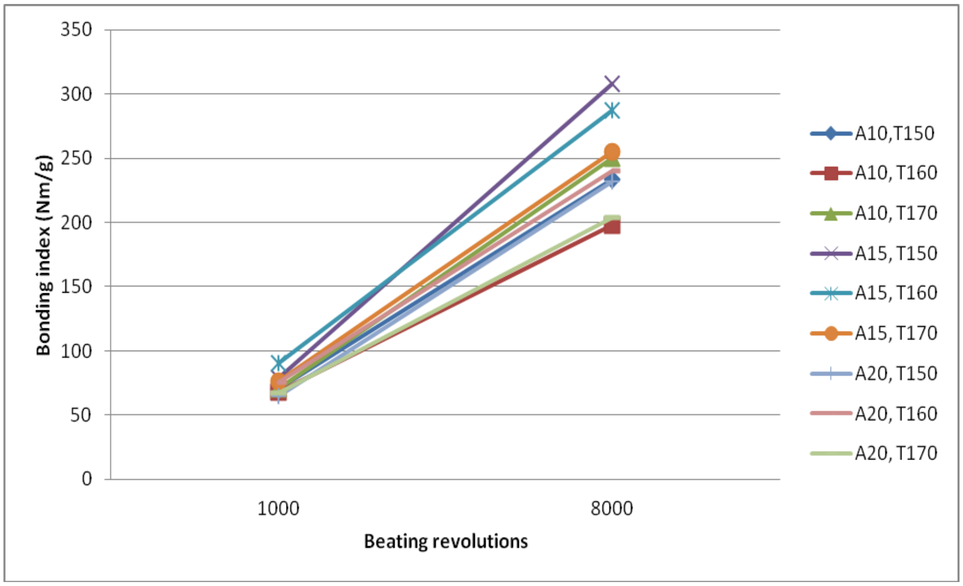

Figure 8. Fibre Bonding Index for 1000 and 8000 beating revolutions

Table 4. Summary of ANOVA for Semantan bamboo paper mechanical properties

Variables	df	Folding endurance	Tearing Index	Tensile Index	Bursting Index	Zero-span Index
Alkaline (A)	2	9.376**	51.965**	87.657**	37.797**	31.583**
Temperature (T)	2	4.966*	8.416**	5.656**	3.544ns	7.024*
Beating (B)	1	123.466**	506.299**	$4.348x10^{3}$**	$2.747x10^{3}$**	9.259*
A*T	4	1.614ns	3.143ns	8.118**	2.284ns	1.510ns
A*B	2	8.639**	3.798ns	4.047ns	8.143*	0.981ns
T*B	2	4.231*	0.993ns	2.260ns	0.013ns	0.135ns
A*T*B	4	1.286ns	2.291ns	1.606ns	0.569ns	0.556ns

Note:** - highly significant, *- significant, ns - not significant

Conclusion

Based on the studies conducted, it was found that the paper mechanical properties for the optimum condition (15% of alkali charge and 150^{o}C of pulping temperature) are as follows. Tensile index at 87.71 Nm/g, bursting index at 6.94 kPa.m^{2}/g, tearing index at 12.72 mN.m^{2}/g and folding endurance at 613 double folds. It can be concluded from these findings that comparable high strength paper can be produced from Semantan bamboo pulp with more environmentally friendly pulping process.

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