The Properties of Bamboo and Old Corrugated Containers Pulp Mixture

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Abstract

The objective of this research was to determine the optimum freeness of virgin bamboo pulp capable of increasing pulp mixture strength and decreasing the quantity of old corrugated containers (OCC) pulp substitution in the mixture. OCC was soaked for 7 days and disintegrated afterward. Soda pulping of bamboo (*Gigantochloa apus*) was carried out following the pulping parameters of 35% NaOH charge, L:W of 4:1, maximum temperature of 170 ^{o}C and total cooking time of 3 h. Kappa number and pulping yield were determined based on TAPPI T236 cm-85 standard. Bamboo and OCC pulp was bleached following the method of $D_0ED_1D_2$. Bleached bamboo pulp was beaten up to the freeness of 100, 200, 300, and 400 ml CSF. While that of OCC was up to 400 ml CSF only. The compositions of bamboo and OCC pulp mixture (B:K) were 0:100, 20:80, 40:60, 60:40, 80:20, and 100:0. Physical and optical properties of pulp mixture were determined based on TAPPI T205 sp-02 standard. The pulp composition of (B:K) 20:80 at freeness level of 400 ml CSF was resulted in the highest strength properties based on Duncan scoring. Pulp beating was able to decrease the composition of bamboo pulp in pulp mixture while retaining the strength properties.

Key words*:* bamboo, beating, freeness, old corrugated containers, pulp composition

Introduction

Recycled fiber has been an important raw material for the pulp and paper industry. At the end of the 2005, the utilization of recycled fiber has increased approximately up to 70% (Cabalova *et al.* 2011). Even though its share tended to increase, due to the diminution of its bonding potential, recycled fiber has been used in addition to virgin fiber in most of pulp and paper products.

Repeated mechanical treatments, chemical treatment and drying bring about a permanent structural change of pulp fiber (Dienes *et al.* 2004). The change has been well known as the origin of the reduction of strength properties dependent on inter-fiber bonding such as bursting, folding and tearing strength. However, recycling of pulp up to 3 cycles has been reported to increase tearing resistance of pulp (Sheikhi & Talaeipoul 2011).

Old corrugated containers (OCC) have been recognized among the most potential source of recycled fiber due to its quantity and collectability. As for other recycled fibers, OCC pulp also retains less satisfying strength properties. However, substitution method can be approached to improve the strength properties of recycled OCC based pulp and paper products. It has been reported that optimum strength of the mixture between OCC pulp and virgin bamboo pulp was obtained at the virgin pulp content of 70% (Wistara & Hidayah 2010). The quantity of virgin fiber for optimum strength of pulp mixture found by these authors can be considered too high mainly from the point of view conserving the nature. Therefore, endeavors need to be carried out to increase the strength properties of both recycled pulp and the virgin fibers to reach a less content of virgin fiber in the mixture without losing the strength properties of the pulp mixture. It has been well understood that the strength properties of recycled pulp is very difficult to be improved compared to that of virgin pulp. Thus, improvement of bonding potential of the virgin pulp was preferred in the present works. Various methods have been developed to improve the bonding potential of virgin pulp. However, mechanical treatment (i.e. beating process) has been the simplest, and considered better than chemical treatments (Sheikhi & Talaeipoul 2011).

Pulp beating brings about external fibrillation, internal fibrillation, fiber shortening, and secondary fines formation. Secondary fines retain higher surface area and water retention capacity. These properties promote better inter-fiber bonding and thus improve the mechanical strength of pulp sheet. Severe beating level improves the quantity of fine formation. Increasing the freeness of pulp from 740 to 340 ml CSF increased specific surface area, water retention capacity, and tensile strength of about 100, 160, and 190%, respectively (Banavath *et al.* 2011). Furthermore, external fibrillation of 0.3-0.7% has been reported to increase tensile strength and internal bonding of pulp sheet as much as 20-46% (Kang 2007). Jimenez *et al.* (2009) has claimed capable of increasing tensile strength of pulp from oil palm empty frond by beating treatment. Pulp also contains primary fines from degraded parenchyma cell during pulping processes. However, primary fines is deficient of bonding potential and therefore do not contribute to the strength properties improvement.

Previously mentioned findings clearly indicate that mechanical treatment is beneficial to improve the strength properties of pulp. Therefore, it was considered worth to evaluate the possibility of strength improvement of OCC and virgin bamboo pulp mixture through refining of the virgin bamboo pulp. Improvement of bonding potential of virgin bamboo pulp was expected to increase the contribution of OCC pulp in the mixture without forfeiting the optimum strength of pulp mixture. The present research was intended to determine the optimum freeness of virgin bamboo pulp capable of increasing pulp mixture strength and at the same time decreasing the quantity of OCC pulp substitution in the mixture. Higher degree of recycled pulp utilization in pulp and paper products is more environmentally sound.

Materials and Methods

The stage of endeavors carried out in the present works included OCC re-pulping, soda pulping of bamboo, pulp bleaching, beating and freeness measurement, pulp mixing, and measurement of optical and strength properties of pulp. Re-pulping was done by soaking in water until the OCC was fully wetted and then agitated, washed and screened with a 200 mesh sieve. The resulting pulp was air dried before storage.

Before pulping, bamboo was chipped into the average size of (3x2.5x0.5) cm^3. The predetermined moisture content of chips was cooked by soda process under the following conditions: maximum temperature of 170 ^oC, L:W of 4:1, active alkali of 35% (as NaOH), and total cooking time of 3 h (i.e. 90 min for impregnation and 90 min cooking at the maximum temperature). The preferred pulping conditions were referring to those used previously by Khamthai (2007). The resulting pulp was washed, screened and stored to be used for the succeeding stage of the research. Kappa number of pulp was measured based on the procedures of TAPPI T 236 cm-85 (TAPPI 1985) standard. The procedure was slightly modified into micro Kappa measurement, in which 25 ml instead of 100 ml of $KMnO_4$ was used. Virgin bamboo pulp and the OCC pulp were bleached following the $D_0ED_1D_2$ bleaching stages. Bleaching conditions and parameters are listed in Table 1. At the end of the last bleaching stage (D_2), the pulp was screened through a 150-200 mesh sieve. Bleached bamboo pulp was then beaten in a PFI beater machine to reach pulp freeness of 100, 200, 300, and 400 ml CSF. The OCC pulp was also beaten to a freeness of 400 ml CSF. Freeness measurement was carried out in accordance with TAPPI T 227 om-99 (TAPPI 1999). Bleached virgin bamboo pulp and bleached OCC pulp were mixed with the composition of bamboo pulp to OCC pulp (B:K) of 0:100, 20:80, 40:60, 60:40, 80:20 and 100:0 (%:%). Pulp mixture was then formed into handsheet following the procedure of TAPPI T 205 sp-02 standard (TAPPI 2002).

The strength properties of pulp measured included tensile strength, bursting strength, and tearing strength. These properties was measured based on the standard procedures of SNI ISO1306-2009 (BSN 2009), SNI ISO2758-2011 (BSN 2011), and SNI ISO 0436-2009 (BSN 2009), respectively. The optical (brightness) and viscosity of pulp were determined following the standard procedures of SNI ISO 2470-1-2010 (BSN 2010) and TAPPI T 230 om-94 (TAPPI 1994), respectively.

Fiber properties of pulp was tested by the used of fiber optic tester Lorentzen and Wattre. Pulp fiber was diluted to a suspension of 0.1% consistency. The suspension (100 ml) was transferred into a Beaker and set up on the instrument's sample holder. The instrument was then automatically sucked the suspension and analyzed the fiber coarseness, fiber length, fiber diameter, and the degree of fiber kink.

The resulting data were analyzed with 2 factors completely randomized design. The first and the second factor were the mixture composition and the freeness of bamboo pulp, respectively. Each factor was consisted of two replicates. Experimental level was 20, 40, 60, 80, and 100%. Data analysis was carried out by the software of SPSS 16.1 for windows with Duncan advance test.

Table 1 Pulping conditions of virgin bamboo and OCC pulp

Parameters	D_0	E	D_1	D_2
ClO_2 (% as Cl_2)	0.22x KN	-	-	-
ClO_2 (%)	-	-	1	0.5
NaOH (%)	-	1	-	-
Consistency (%)	10	10	10	10
Temperature (ºC)	60	70	75	75
Time (min)	60	60	180	180

Results and Discussion

The yield and kappa number of pulp

The average screened yield of pulping in the present experiment was 30.16% with the kappa number of 26.35. Previous works with the same pulping conditions (Khamthai 2007) resulted in the pulping yield of 56% with the kappa number of 30.5. In term of pulping selectivity, the current pulping experiment (with pulping selectivity of 1.4) was less selective compared to that previously done (pulping selectivity of 1.8). Pulping selectivity could be influenced by the age and growing site of bamboo. In the present work 5 years old Indonesia bamboo instead of 3 years old Thailand bamboo (Khamthai 2007) was used. Vu *et al.* (2004) has also revealed that bamboo species influenced its pulping selectivity. These authors have pulped Vietnam bamboo (*Bambusa proceraacer*) by soda process with 17% active alkali (average) at 165 ^{o}C of maximum temperature for 3 h total cooking time. They found the yield of 50.5% and the kappa number of 22.5. Soda pulping selectivity can be improved by the addition of additive such as anthraquinone (AQ). Soda-AQ pulping of bamboo has dramatically reduced kappa number of pulp to 11.8 while maintaining high pulping yield of 55.6% (Khamthai 2007).

The cell type and composition of bamboo was also thought to influence its pulping yield. In general, bamboo consisted of 50% parenchyma cell, 40% fiber and 10 vessel cells (Dransfield & Widjaya 1995). Parenchyma and vessel cell are degraded and dissolved in alkaline pulping processes such that of kraft and soda pulping. Therefore, the high total content of parenchyma and vessel cells in bamboo could be attributed to the low pulping yield of the present result.

Optical properties (brightness) of pulp

Brightness indicates the quantity of light reflectance by a material relative to that by a standard material (Titanium Oxide) in % ISO or ^{o}GE. OCC pulp influenced the brightness of pulp mixture as indicated by Figure 1.

Pulp composition significantly influenced the brightness of pulp mixture, but not with the pulp freeness. Figure 1 indicates that brightness of pulp mixture tended to decrease with the increasing of OCC pulp content. This is indeed due to the low brightness of OCC pulp, which was only 43% ISO. The brightness of bamboo pulp was ranged from 46 to 69% ISO. Brightness of pulp and paper products can be increased through the addition of additives such as optical brightening agents (OBA) and Fluorescent Whitening Agents (FWA). A 3% increase in the brightness of paper containing 20% high yield kraft pulp has been achieved by a 0.4% increased of OBA content (Zhang *et al.* 2009). Oxygen and peroxide stages are also capable of increasing pulp brightness. Wang *et al.* (2012) produced oil palm frond pulp with the brightness of 83% ISO by the application of O and P stages in their TCF bleaching method.

Fiber characteristics

Fiber dimension and its derivative value influence the strength properties of pulp and paper sheets. Long fiber with thin cell wall and large lumen diameter tends to produce strong paper. Fiber characteristics of bamboo and OCC pulp (both beaten and unbeaten) are shown in Table 2.

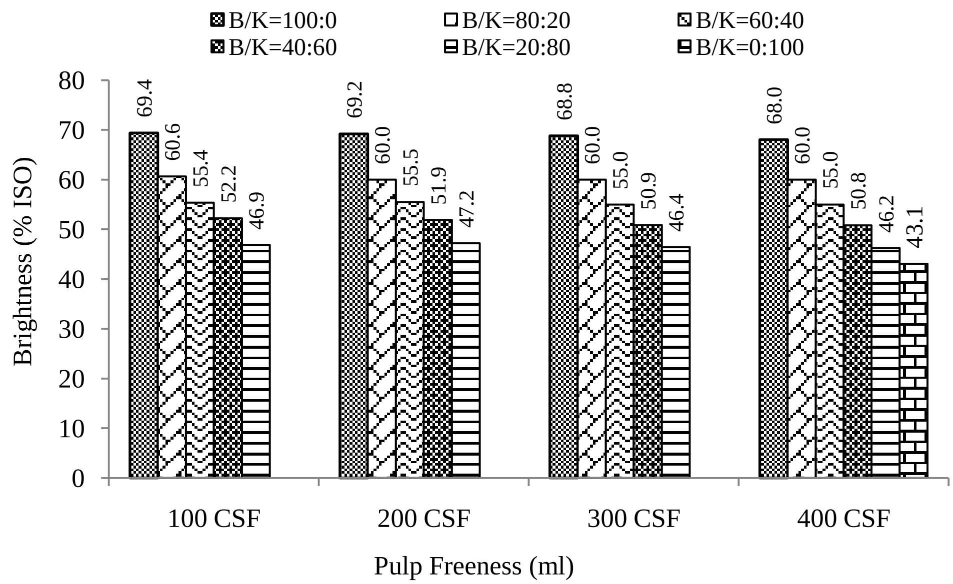

Figure 1 The brightness of pulp mixture.

Pulp beating brings about fiber shortening, external fibrillation, and internal fibrillation. Fiber shortening is clearly indicated by Table 2, in which fiber length of bamboo pulp decreased from 1.8 to 1.03 mm upon beating process. Mechanical shearing force was attributed to the fiber shortening process (Chen *et al.* 2011).

In the present works, fiber shortening was not occurred for OCC pulp fibers possibly due to the fibers had already very short and the OCC pulp was not subjected to severe mechanical action (OCC pulp was beaten up to 400 ml CSF only). The occurrence of internal fibrillation is visible through the increasing of fiber diameter both in bamboo and OCC pulp fibers. Coarseness reduction and internal fibrillation after pulp beating can increase the flexibility of the fibers. Wistara and Effendi (2011) found that the flexibility ratio of bleached mix tropical hardwood pulp increased after beating.

Tensile strength

Tensile strength measurement is intended to understand the capacity of pulp and paper to stand direct tensile stress. Figure 2 shows tensile strength of pulp at various level of pulp freeness. It can be seen that pulp composition of (B:K) 20:80 retains the highest tensile index (42.33 Nm g^{-1}) at freeness level of 300 ml CSF. Statistical analysis indicated that pulp composition was the only factor that significantly influenced tensile strength. At B:K of 20:80, tensile strength of pulp satisfied the requirement of SNI ISO 1306-2009, which is of 30 Nm g^{-1} for bleached kraft hardwood pulp. Previously, pulp composition (B:K) of 70:30 at the freeness level of 400 ml CSF was reported to result in the highest tensile strength (Wistara & Hidayah 2010).

It seemed that beating of pulp from 400 ml CSF to 300 ml CSF succeeded to reduce the content of virgin bamboo pulp without giving away the tensile strength of pulp mixture.

Table 2 The characteristic of beaten and unbeaten bamboo and OCC pulp fiber (OCC pulp was beaten up to 400 ml CSF only)

Fiber characteristics	Unbeaten pulp		Beaten pulp	
	Bamboo	OCC	Bamboo	OCC
Fiber length (mm)	1.80	1.11	1.03	1.11
Fiber diameter(µm)	19.60	24.30	22.40	24.90
Coarseness (µg m^{-1})	371.90	554.30	0.10	31.40
Kink angle (degree)	63.41	50.04	66.89	46.83
Kinks quantity (mm^{-1})	1.12	0.60	0.80	0.41
The quantity of large kink	0.52	0.17	0.33	0.09

This was thought due to the increasing of bonding potential of virgin bamboo pulp. Internal fibrillation promote bonding potential improvement, and the increased of beaten fiber diameter from 19.6 to 22.4 µm and the decreased of fiber coarseness from 371.9 to 0.1 µg m^{-1} after beating are indicative to the occurrence of internal fibrillation. The present finding ensures that pulp beating to a higher freeness level is paramount to improve bonding potential of pulp, and thus the tensile strength. Wanrosli *et al.* (2005) failed to develop better bonding potential of virgin pulp of the palm oil empty frond by 1000 revolution. They required 80% virgin pulp of palm oil empty frond component in a mixture with OCC pulp to gain higher tensile strength.

Bursting strength

In principle, tensile and bursting strength are determined by the same factors, i.e. inter-fiber bonding quality. These two strength properties are different in measurement loading direction. In tensile strength measurement, tensile load is applied parallel to the testing samples plane, while in bursting strength measurement, the load is applied perpendicular to the sample plane.

Figure 3 indicates that the highest bursting strength (2.71 kPa m^2 g^{-1}) is retained by pulp composition (B:K) of 20:80 at 100 ml CSF freeness level, which is higher than a minimum of 2 kPa m^2 g^{-1} required by SII 0830-83. Bursting strength was significantly influenced by pulp composition.

Tearing strength

The capacity of pulp to stand tearing strength during its conversion or final application is measured as tear index. Figure 4 indicates the relationship between tearing strength and the freeness of pulp.

The composition and freeness of pulp significantly influenced the tear indices of pulp mixture. Tearing strength of pulp mixture with the composition (B:K) of 20:80 at the freeness level of 400 ml CSF reached 9.5 mN m^2 g^{-1} higher than that a minimum of 5 mN m^2 g^{-1} required by SNI ISO 0436-2009 for tropical hardwood bleached pulp. It can be seen from Figure 4 that tear indices tended to increase with decreasing of virgin bamboo pulp freeness. Fiber length has been attributed to strongly influent tearing strength of pulp. Longer fiber tends to increase tearing strength due to that long fiber retains higher possibility of fiber networking in the handsheet (Ghasemian *et al.* 2012). Table 2 indicates that pulp beating up to 400 ml CSF decreased fiber length from 1.80

mm to 1.03 mm. Even though fiber length measurement was not conducted for pulp at higher freeness, increasing the intensity of beating was thought further decreased the fiber length of pulp. Therefore, the decreasing composition of bamboo pulp and the increasing of pulp freeness was possibly the origin of increasing tearing strength of pulp mixture. Pulp beating to a higher freeness brought about higher external and internal fibrillation of pulp fiber and consequently increased its inter-fiber bonding potential. The increase of inter-fiber bonding tends to decrease tearing strength of pulp (Fatehi *et al.* 2010).

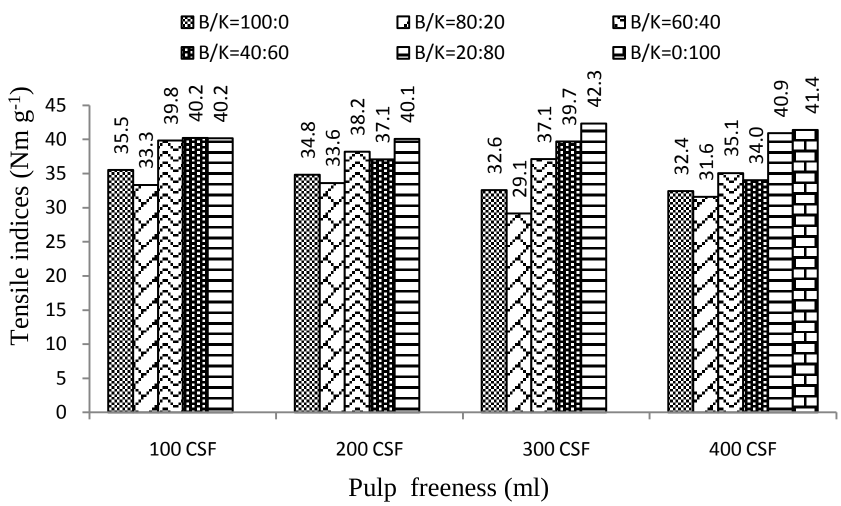

Figure 2 Tensile indices of virgin bamboo and OCC pulp mixture at various composition and freeness of pulp.

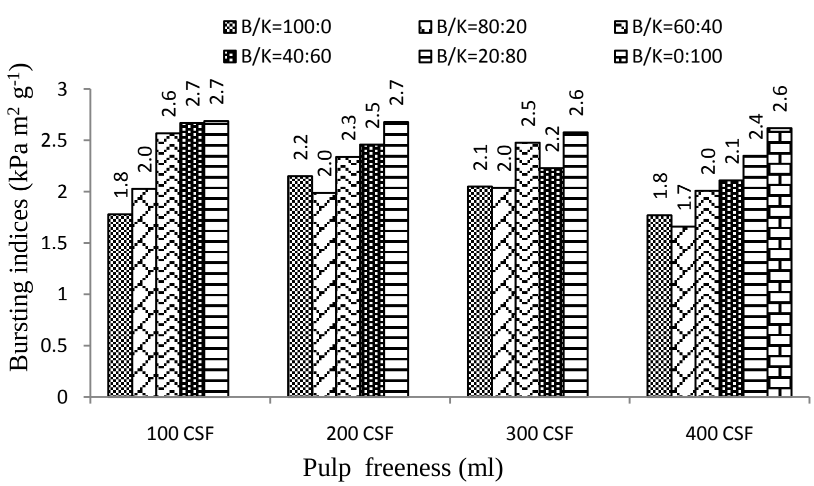

Figure 3 Bursting indices of virgin bamboo and OCC pulp mixture at various compositions and freeness level of pulp.

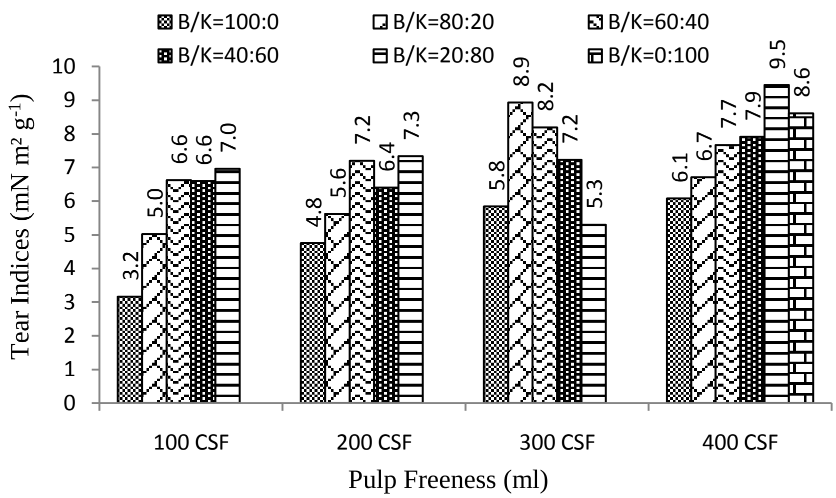

Figure 4 Tear indices of virgin bamboo pulp and OCC pulp mixture at various pulp composition and freeness degree.

Table 3 The viscosity of bamboo and OCC pulp at different freeness degree

Pulp	Pulp viscosity (cps)				
	Unbeaten pulp	100 ml CSF	200 ml CSF	300 ml CSF	400 ml CSF
Bamboo pulp	5.11	4.60	4.66	4.74	5.13
OCC pulp	8.93	-	-	-	8.76

Pulp viscosity

The viscosity of pulp represents the polymerization degree of cellulose. It is also predictive of cellulose degradation degree. Therefore, it is very common to use pulp viscosity to predict the strength properties of pulp. Joutsimo (2004) found that at low pulp viscosity, alkaline degradation on cellulose influenced pulp strength. The measurement results of bleached pulp viscosity of the present works are listed in Table 3.

The viscosity of unbeaten pulps was higher than those of beaten pulps indicating that increasing intensity of pulp beating brought about degradation of cellulose polymer. Although degradation of cellulose polymer has been understood to decrease individual fiber strength as well as the strength of pulp handsheet (Spiridon & Duarte 2002), strength properties found in the present research indicated that an optimum viscosity existed for maximum strength development of pulp.

Conclusion

The composition mixture between virgin bamboo pulp and OCC pulp (B:K) of 20:80 at the freeness of pulp of 400 ml CSF resulted in the best strength properties based on Duncan scoring. Pulp composition significantly influenced the strength and optical properties of pulp mixture, and the degree of freeness only influenced tensile and tear strength of pulp. OCC pulp and the degree of freeness were more dominant to increase inter-fiber bonding potential of pulp mixture.

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