An Optimum Mixture of Virgin Bagasse Pulp and Recycled Pulp (OCC) for Manufacturing Fluting Paper

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This study evaluated the properties of fluting paper made with a blend of unbleached bagasse soda pulp (340 mL CSF freeness) and OCC pulp (250 to 300 mL CSF freeness) of 0:100, 10:90, 30:70, 50:50, 70:30, and 90:10 ratios by weight, respectively. Some handsheets at 120 g/m^2 basis weight were made. Strength characteristics such as tear index, tensile index, air resistance, double folds, burst index, and Concora medium test (CMT) were measured according to TAPPI and ISO standards and compared to each other. Inferior handsheet properties were observed when using 100% recycled fibers. Results further showed that addition of 10 to 30% bagasse pulp to OCC pulp did not significantly enhance the sheet strength of the product compared with the control sample (100% OCC pulp). However, it was found that addition of 70% or more of virgin pulp to the OCC pulp resulted in a substantial increase in the strength properties, except for the tear index. The modification of the fibers was visually evaluated by Scanning Electron Microscope (SEM). Overall, the results showed that flexible virgin bagasse fibers can be used as a lignocellulosic fiber for making fluting paper in combination with recycled OCC fibers.

Keywords: Old corrugated container (OCC); Strength characteristics; Scanning electron microscope; Virgin pulp; Bagasse; Fluting paper

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INTRODUCTION

Demand for paper and paperboard is increasing, and resources are insufficient for market demands. The world demand for mentioned products is estimated to reach 490 million tonnes by 2020, with an average annual growth rate of 2.8% (Agnihotri *et al.* 2010). In addition to wood resources, other cellulosic sources such as non-wood fibers, especially agricultural waste, along with used papers or paperboards, have been used in pulp and paper industry as less expensive sources of material. To achieve optimal results when using the recycled fibers, they can be combined with virgin fibers in different ratios. In this research, blends of recycled pulp (*i.e.*, old corrugated container) and virgin bagasse pulp were utilized for manufacturing fluting paper.

The application of old corrugated containers (OCC) as a recycled fiber for paper manufacturing can somewhat compensate for the shortage of virgin cellulose resources, and can be instrumental in decreasing energy consumption and environmental pollution. The American Forest & Paper Association (AF&PA) released the 2011 recovery rate for old corrugated containers, which reached a new high of 91.2%. Old corrugated containers are abundantly available and easily accessible. Old corrugated container material is a potential source of secondary fibers. However, some supplies of OCC are composed mainly of short fibers, which will result in inferior paper strength (Minor and Atalla 1992).

One shortcoming of the recycling process is the strength properties of the paper decreases due to fiber hornification. The latter refers to a chemical condition resulting from the drying and rewetting cycle of the fibers, which in turn, results in an irreversible loss in fiber swelling capacity of the cell wall (Jayme 1958). On the other hand, the refining process for the recycled fibers leads to breakage of brittle fibers into smaller fibers and fines. Therefore, to compensate for these deficiencies or to restore fiber bonding strength, some methods have been used (Howard 1990). These methods include mechanical or chemical treatment of the recycled fibers (Zanuttini *et al.* 2009; Freeland and Hrutfiord 1994), fractionation and pre-treatment of the recycled fibers with enzymes (Biricik and Atik 2012), and blending of the recycled fibers with virgin fibers (Sarkhosh Rahmani and Talaeipoor 2011; Ghasemian *et al.* 2011; Wistara and Hidayah 2010). In the current research, blending OCC recycled pulp with virgin bagasse pulp was selected as a method for manufacturing fluting paper. Fluting paper consumption in Iran was more than 175,000 tons in 2010, of which 20,000 tons was supplied by imports and the rest was provided internally (Barimany Aboksari *et al.* 2013).

Sugar cane is a perennial plant grown primarily for the juice extracted from its stalks. It is harvested annually. The canes are crushed to yield fibers that are 1.0 to 1.5 mm in length and 20 microns in diameter. These fibers are similar to hardwoods, such as eucalyptus, which is 0.7 to 1.3 mm in length and 20 to 30 microns in diameter (Covey *et al.* 2006). Kiaei *et al.* (2011) investigated the biometry, morphological properties, and chemical compositions of agricultural residues, such as bagasse, corn, sunflower, rice, and rapeseed. The results showed that bagasse had the greatest proportion of fiber length (1.32 mm) and cellulose content (55.56%), along with a low ash (1.78%) and lignin (20.5%) content. Also, fiber diameter and wall thickness governs the fibers' flexibility. Thin walled fibers favorably affect the burst strength, tensile strength, and folding endurance of the paper (Dutt and Tyagi 2011). It has been found that bagasse fibers have a high flexibility ratio (Kiaei *et al.* 2011).

Also, much research has demonstrated, regardless of the process employed to manufacture bagasse pulp, that the end-products have good formation, in particular appropriate surface smoothness and sufficient strength (Zanuttini 1997; Lam *et al.* 2004; Khristova *et al.* 2006; Abou-Yousef *et al.* 2005; Hurter 2007; Huang *et al.* 2008; Khakifirooz *et al.* 2011). This is further aggravated by the recent deforestation trend in the world, which places an added pressure on the supply side, prompting measures to compensate by using cellulose from alternative sources, such as agricultural residues.

Now, how can the quality of OCC recycled pulp be increased? Various studies have been undertaken to overcome the loss in paper strength by mixing recycled pulp with non-wood virgin pulp. Wistara and Hidayah (2010) improved the strength of OCC recycled pulp by blending in some virgin pulp. They found that a 70% substitution of OCC recycled pulp with virgin bamboo pulp resulted in the preferred strength properties. Garg *et al.* (2008) utilized wheat straw pulp as the reinforcing aid for recycled softwood pulp. The results showed that wheat straw pulp enhanced the strength of recycled pulp and that blends containing about 40 to 60% wheat straw pulp offer the best combination of tensile and tear strength.

Sarkhosh *et al*. (2011) investigated the production of fluting paper from wheat straw pulp (produced by soda–AQ) and OCC pulp blended in ratios of 25, 50, and 75%.

Their research showed that addition of 75% wheat straw pulp to OCC pulp can considerably enhance the physical properties and strength properties of the fluting. In another study, Ghasemian *et al*. (2011) evaluated the properties of handsheets made from recycled OCC and virgin neutral sulfite semi-chemical (NSSC) pulp. The handsheet samples contained a series of mixtures of OCC and virgin NSSC pulp (0:100, 20:80, 30:70, and 40:60 by weight). Their research showed that increasing the amount of OCC fibers significantly enhanced paper strength properties, which the authors attributed to increased cationic starch adsorption efficiency since OCC fibers have more specific surface area than NSSC fibers, thus facilitating greater adsorption rate of the cationic starch.

Recycled OCC pulp blended with virgin bagasse pulp could result in improved mechanical strength of the final mixed pulp. If the recycled OCC pulp properties can be improved, then a lower the amount of OCC waste will be discharged to the environment. Considering that a partial substitution can improve strength properties of recycled OCC pulp, the present research was intended to increase the strength properties of recycled OCC pulp *via* partial substitution with virgin bagasse pulp. The most appropriate composition of OCC pulp and bagasse pulp to produce the best strength properties was also determined.

EXPERIMENTAL

Materials

OCC pulp was obtained from Mazandaran Wood and Paper Industries located in Mazandaran, Iran. The freeness of pulp (TAPPI method T 227 om-94) was 250 to 300 mL. The raw material for the OCC was old corrugated carton and packaging paper (about 95%) with some mixed office papers (about 5%). Unbleached bagasse pulp was produced at Pars Paper Company located in Haft Tapeh, Khuzestan, Iran, by the following pulping processes:

- Soda, chemical material content: NaOH, 15% (based on oven dried bagasse)
- Cooking temperature: 170 °C
- Digester pressure: 7 bar
- Time cooking: 15 min
- Freeness: 570 mL
- Kappa number: 9 to 11

The resulting bagasse pulp was refined with a valley beater to a freeness of 340 mL. The consistency of both pulps was calculated according to Equation 1,

$$cons\% = \frac{m_0}{m_h} \times 100 \qquad (1)$$

where m_0 equals the mass of the dried sample, and m_h equals the mass of the wet sample. Three consistency measurements were performed for each pulp to calculate the average value. The consistency of the bagasse pulp and the OCC pulp were 22% and 16%, respectively. Then, 109 g of the bagasse pulp and 150 g of the OCC pulp were separately defibrated with a disintegrator (5 min and 5000 revolutions). After defibration, some water was added to each pulp to form an 8000 mL suspension. The method involved adding unbleached bagasse soda pulp to an OCC pulp suspension at different percentages (10, 30, 50, 70, and 90%). Each handsheet (120 g/m^2) was made using 800 mL of pulp suspension (Table1).

Table 1. Different Mixtures of Suspensions for OCC and Bagasse Pulps

Mass ratios, wt. % OCC to bagasse pulp	OCC pulp suspension (mL)	Bagasse pulp suspension (mL)
100:0	8000	-
90:10	7200	800
70:30	5600	2400
50:50	4000	4000
30:70	2400	5600
10:90	800	7200
0 :100	-	8000

Testing Methods

Handsheets were made in a L & W handsheet former according to TAPPI T 205 sp-02 standard to evaluate the characteristics of various mixtures. Seven handsheets, each with a 200 cm^2 area and basis weight of 120 g/m^2, were made for each treatment. The samples were conditioned at 50±2% relative humidity and 23±1°C according to TAPPI T 402 sp-03 for at least 24 h before performing strength tests.

Handsheets were cut according to TAPPI Standard T 220 sp-01 for physical properties measurement. Various test methods, consisting of tensile index (ISO-1924-2), tear index (ISO -1974), burst index (ISO - 2758), corrugating medium test (CMT, ISO - 7263), air permeability (ISO- 5636-5), and double fold (TAPPI method T 511 om-02) were used for the analysis of the sheets.

Scanning Electron Microscopy (SEM)

Scanning electron microscopy (KYKY-EM3200 model) was used for studying the morphology of the fibers of the handsheets. All images were taken at 25 kV strike power. Prior to the analysis, the surface was coated with gold, which was carried out by a SCD005 sputter coater.

Statistical Analysis

The handsheet properties experiment was done as a completely randomized design with seven pulps as treatments. Analysis of variance and Duncan tests were done to show significant differences between treatments. Statistical procedures were carried out using SPSS software. The sheet that was made with 100% OCC fibers was designated as the control sample.

RESULTS AND DISCUSSION

Handsheet Properties

The properties of the handsheets obtained from bagasse pulp and OCC pulp are presented in Table 2 and Figs. 1 through 8.

Table 2. Strength Properties of Fluting Handsheets

Composition (B/R) - %	Density (Kg/m^3)	Tensile (N•m/g)	Burst index (kPa•m^2/g)	Tear index (mN•m^2/g)	CMT (N)	Air resistance (s/100 mL)	Double Fold (times)
0:100	461.89^d	17.90^d	0.633^e	5.14*	64.5^e	6.33^d	10^d
10:90	472.47^d	18.40^d	0.917^{de}	5.83*	85.5^e	5.37^d	19^d
30:70	493.45^c	23.07^c	1.2^d	6.14*	95.0^e	12.40^d	26^d
50:50	525.83^c	25.39^c	1.61^c	6.46*	170.5^d	12.70^d	28^d
70:30	608.74^b	32.69^b	1.92^{bc}	6.22*	262.0^C	48.86^c	240^c
90:10	614.45^b	33.48^b	2.21^b	6.00*	298.5^b	65.83^b	342^b
100:0	675.98^a	43.60^a	2.63^a	5.47*	350.0^a	152.67^a	445^a

Note: B = virgin bagasse pulp and R = recycled OCC pulp
*Means within a column followed by different letters are significantly different at α = 0.05

There was no significant increase in the burst and tensile indices of the handsheets prepared by adding 10 and 30% bagasse pulp versus the control sample (Table 2). However, adding 50% or more bagasse fibers had a significant effect on these properties. Since strength properties are dependent on fiber bonding and flexibility, it was expected that the increase in the amount of bagasse fibers increases these properties.

The burst index of pulp comprised of 50:50 and 70:30 (B/R) was found to be as high as 1.62 and 1.92 kPa•m^2/g, respectively (Fig.1). The linear trendline illustrates that burst index had consistently risen by adding more virgin pulp. Notice that the R-squared value was 0.9885, which was a very good fit of the line to the data. Wistara and Hidayah (2010) obtained the highest burst index as high as 1.37 and 1.27 kPa•m^2/g by incorporating 50% and 70% virgin bamboo pulp, respectively; however, that burst index did not conform to minimum requirement of SII 0830-83 for bleached hardwood kraft pulp, which requires a minimum value of 2 kPa•m^2/g. The burst and tensile index is dependent on inter-fiber bonding (Wistara and Hidayah, 2010). Horn (1978) indicated that more flexible fibers provide more area that can be developed for bonding along the fiber's length.

Tensile strength indicates the ability of the pulp to resist tensile forces operated at both of its ends at opposite directions measured under a standard condition. It was found that pulp compositions significantly influenced tensile strength of pulp mixture. Table 2 and Fig. 1 indicate that the highest tensile strength (32.69 N•m/g) was likely obtained by 70:30 (B/R) composition. This was the composition giving the tensile strength that met the minimum requirement (30 N•m/g) of SII 0830-83 standard for bleached hardwood kraft pulp (Wistara and Hidayah 2010). The R-squared value of tensile index was 0.9655, which was a good fit of the line to the data. Therefore, as far as tensile strength is considered, the 30:70 blend was the best mixture between virgin bagasse pulp and OCC recycled pulp. This result was consistent with the results of Wistara and Hidayah (2010). In general, bagasse fibers serve as a bonding component in the mixture. But when the amount of bagasse is low, then there are many places in the sheet where contact is only at weak links between OCC fibers, so the strength remains low. By contrast, addition of a small amount of OCC fibers to virgin fibers (bagasse) immediately causes the tensile strength to drop because weak bonding points are being introduced. The weak joints between the OCC fibers are the likely places where failure is initiated.

In cases where the tear index is important for the product, an addition of 50% bagasse would improve tear index, but higher proportions led to lower tear (Fig. 1). Moreover, the R-squared value was very low ($R^2 =$ 0.0551). Sarkhosh *et al.* (2011) found that blending wheat straw soda-AQ pulp with OCC pulp did not significantly increase the tear index when compared to the 100% OCC pulp. Tear index is mainly influenced by fiber length (Wistara 2010; Horn 1987; Gurnagul *et al.* 1990). Wistara and Hidayah (2010) indicated that increasing inter-fiber bonding only increased tear index to a certain optimum point. Theoretically, short fibers tend to increase inter-fiber bonding up to a certain optimum point, and thereafter will reduce tearing strength.

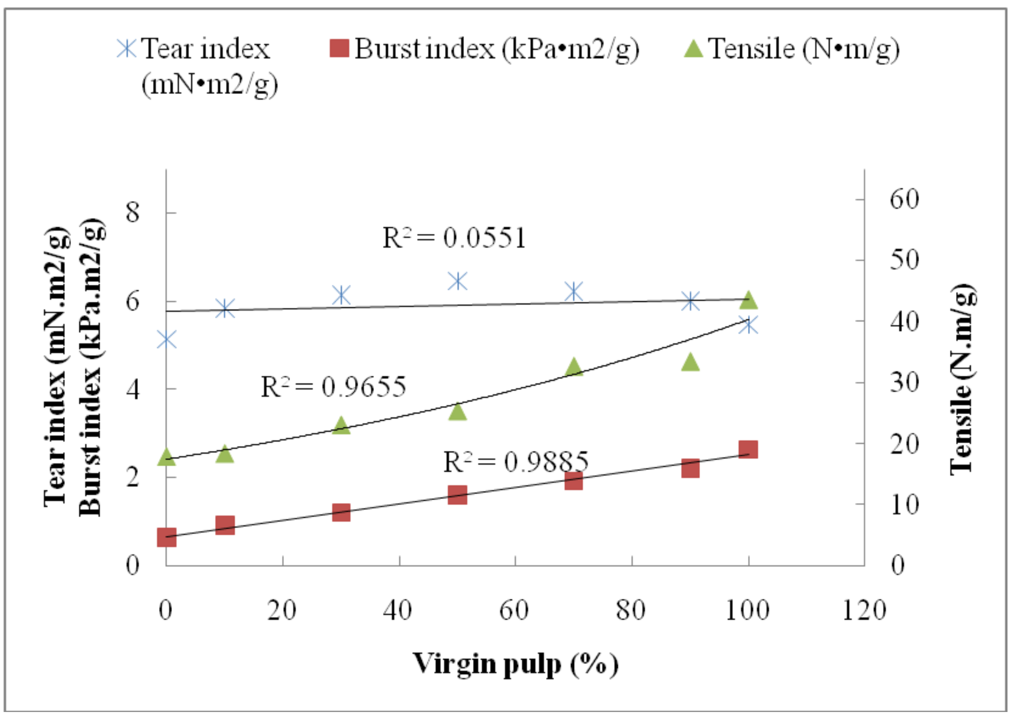

Fig. 1. Influence of virgin pulp on tear, burst, and tensile indices

Tensile test results reflect the intimate structure of paper and the properties of its individual fibers. Figure 2 shows that a fair correlation between sheet density and tensile index was observed. A sheet made of 100% recycled pulp of OCC yielded a very bulky sheet and the lowest tensile index. Increasing density indicated the sheet was more compact due to incorporating more virgin pulp. It can be seen that by increasing the percent of the virgin pulp, the properties such as burst index and tensile index were increased. Also, density is an indication of the relative amount of air in the paper, which in turn, affects the strength properties of paper (Biermann 1996).

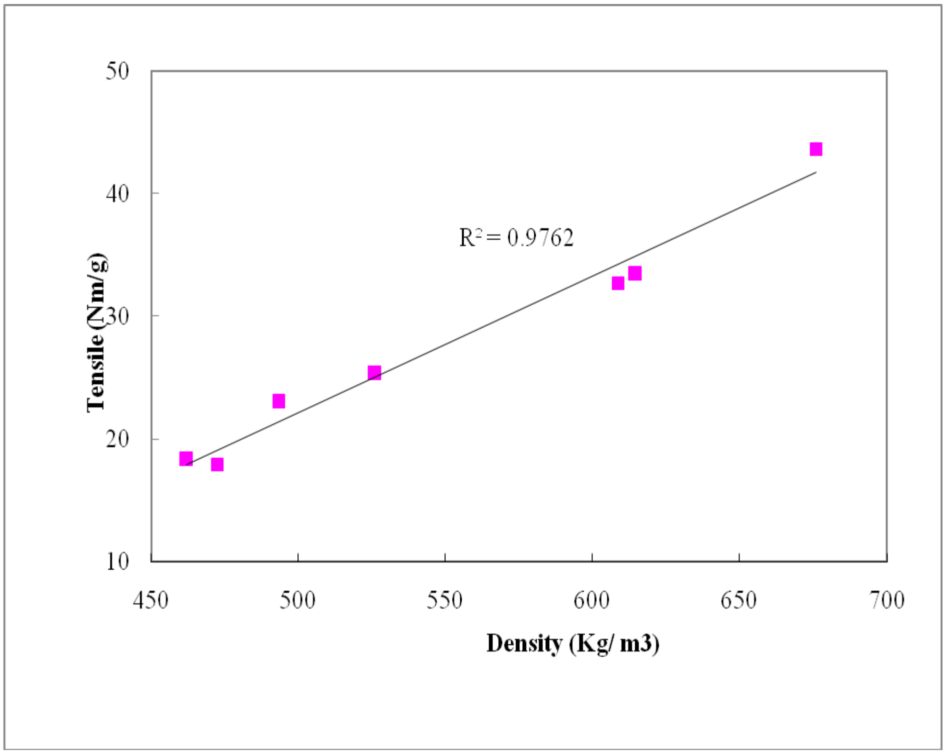

Fig. 2. The relationship between density and tensile index

It was observed from Fig. 3 that by adding the smaller and more flexible bagasse fibers seemed to fill up the voids in the sheet and created more bonding with the more flat fibers.

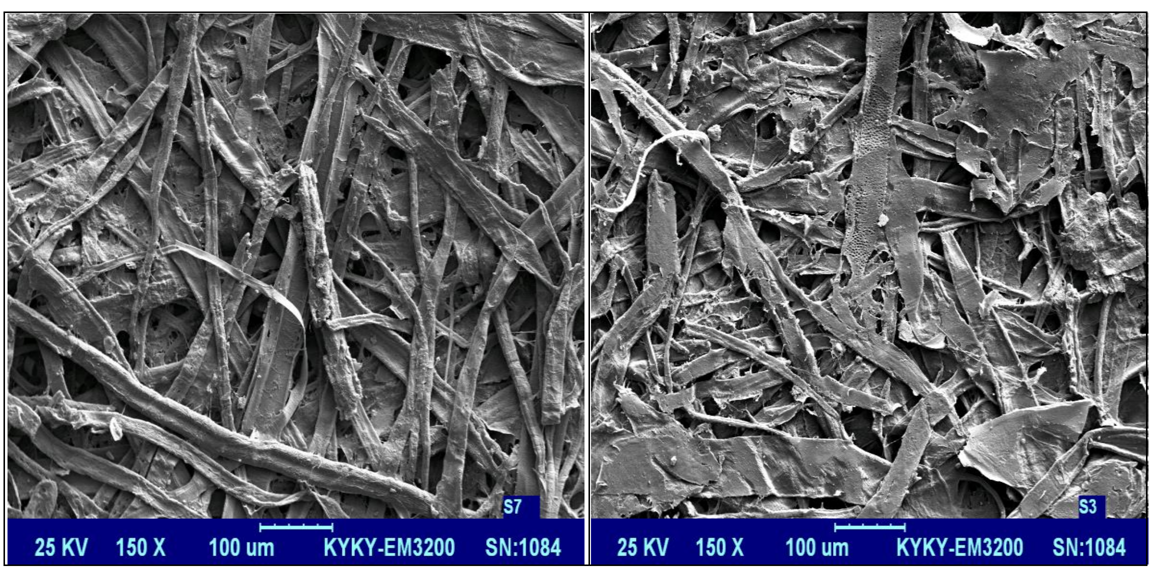

Fig. 3. Scanning electron microscope micrographs of the surface of a handsheet of 100% OCC fibers (left) and composition 70:30 (B/R) (right)

The dimensions and strength of the individual fibers, their arrangement, and the extent of inter-fiber bonding are considered as the most important factors contributing to strength properties (Page 1969; Azizi Mossello *et al.* 2010; Wistara and Hidayah, 2010).

Statistical analysis indicated that an improvement of CMT was not observed by adding 10 and 30% bagasse fiber. However, it can be observed from Fig. 4 that when 70% of bagasse pulp was added to the OCC pulp, CMT increased fourfold (262 N) in comparison to the control sample (65.5 N). Sarkhosh and Talaeipoor (2011) added 75% wheat straw soda-AQ pulp to recycled OCC pulp to reach this amount of Concora medium strength (260 N). The least CMT value was related to the OCC fibers; this was in accordance with the results observed by Ghasemian *et al.* (2011). In fact, the improvement in sheet strength by addition of virgin pulp had a higher impact on CMT than on tensile strength. It seems that the bonding capacity of the pulp is essential for compression properties.

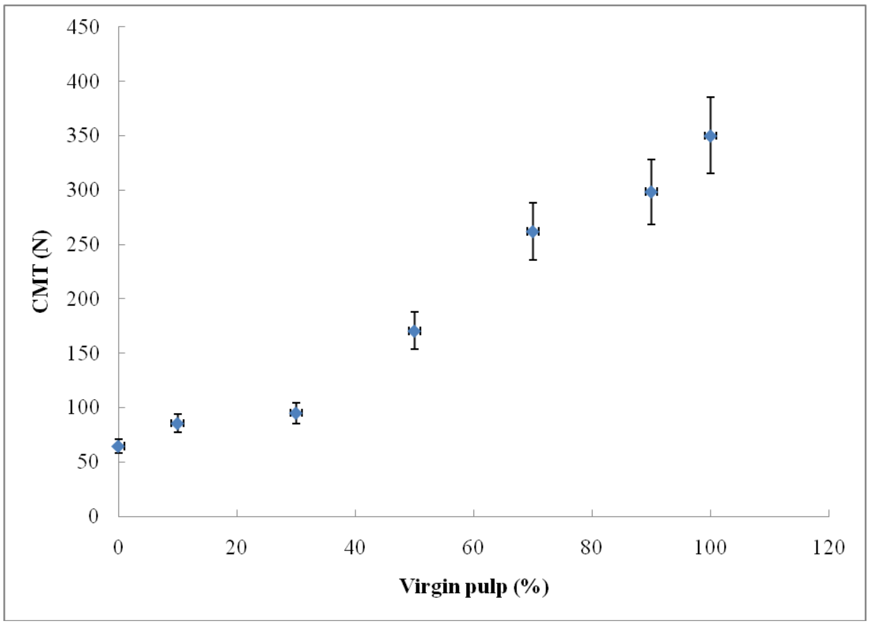

Fig. 4. Influence of virgin pulp on CMT property

Most standard paper tests, such as tensile, burst, and tear do not correlate well to how the corrugating medium will perform as actual boxes, so the medium is fluted in the laboratory and tested to determine the resistance of a laboratory-fluted corrugated sheet (Biermann 1996). The CMT permits the assessment of corrugating medium before it is fabricated into the final product. The edgewise compression strength of corrugated board is a principal element in determining the dynamic compression strength of the container made from a board. Since corrugated containers are frequently subjected to loads which are resisted by compression strength, the CMT is a main measure of the performance characteristic of corrugated board and is useful in measuring the quality of the finished product (Ghasemian *et al.* 2011; Biricik and Atik 2012). The deficiency in Concora strength can be overcome with increased refining (Fang 1977).

A higher number of seconds in the air resistance values means the paper is more resistant to air penetration (Perng *et al.* 2009). Based on Fig. 5 and Table 2, it is clear that the higher content of virgin fibers (more than 50%) resulted in the handsheets having tighter-texture and more air flow resistance. As can be seen from Fig. 5, even using 50% bagasse pulp did not significantly improve the double folds and air resistance characteristics when compared to the control sample. However, by adding 70% virgin pulp, the air resistance (48.86 s/mL) and the double folds (240 times) increased dramatically when compared to the control sample. The fold test is important for papers that are subjected to multiple folds such as books, maps, box boards, cartons, *etc*. Research by Wang *et al.* (2012) substantiates the aforementioned results by showing an inverse relation between the densification of the handsheet and the paper's porosity. In their view, increasing in the densification of handsheet resulted in higher air resistance of the handsheet. Low porosity can affect the runability of corrugating medium, which is necessary to provide and maintain good flute formation (McGrattan 1990).

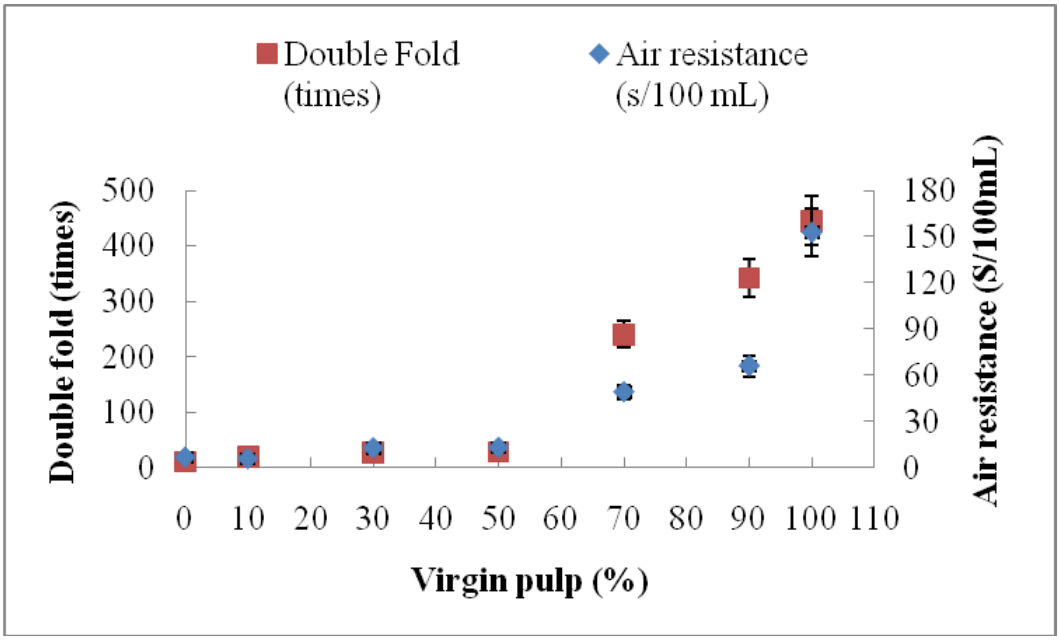

Fig. 5. Double folds and air resistance properties of pulp mixture

The lowest strength was obtained with 100% OCC fibers, which was in accordance with the results of Azizi Mossello *et al.* (2010). The authors found that the OCC pulp had lower strength properties in comparison with kenaf soda-AQ pulp. Figure 6 (right) shows that the OCC pulp consisted of narrow and thick-walled fibers, whereas the bagasse fibers were more flat (Fig. 6, left). In other words, Fig. 6 sufficiently indicated the qualitative difference in OCC fibers being coarse and less collapsed compared to the bagasse fibers. However, Kautto *et al.* (2010) pointed out that compact, narrow and thick-walled recycled fibers are instrumental in forming porous papers. As can be seen in Fig. 6, the contact between fibers of the control sample was lower than of the bagasse fibers. This result was confirmed by strength properties results. Reduced fiber-to-fiber bonding has been reported to decrease the tensile index values and increase the tear index values (Kautto *et al.* 2010). The decrease of the tensile index observed in this study supported the argument that successive recycling of papers tended to decrease the fiber-to-fiber bonding in fiber network.

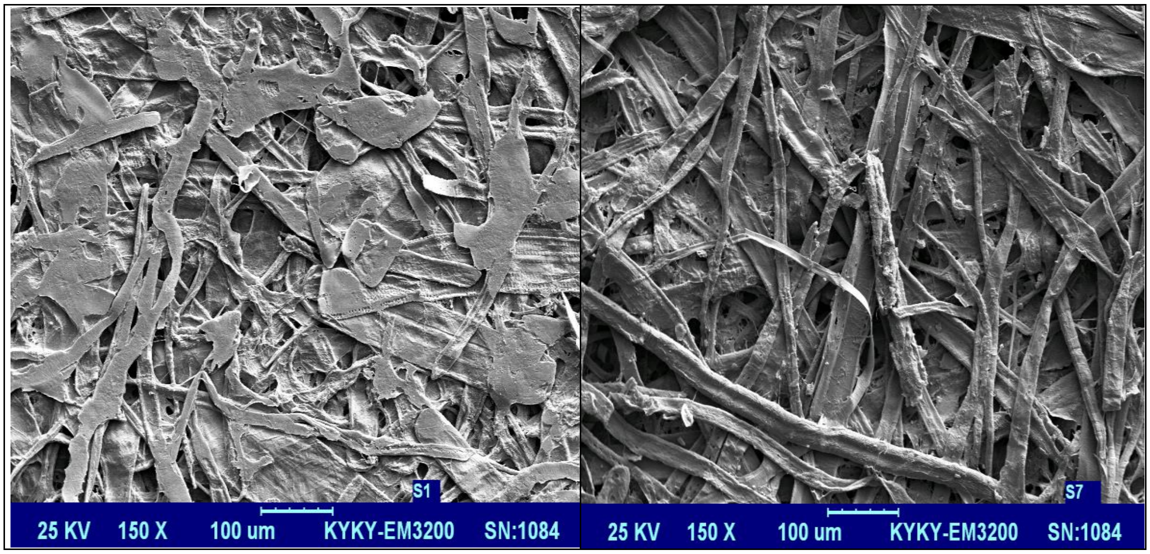

Fig. 6. Scanning electron microscope micrographs of the surface of handsheets of virgin pulp (left) and recycled pulp (right)

Guo *et al.* (2011) pointed out that the paper strength is predominantly determined by the fiber water retention value (WRV). This is due to physical characteristics of the fibers that allow water to percolate through its porous structure, which is the process where the fibers swell. Many pores can be observed on the bagasse fibers (Fig. 7, right), a characteristic which is rarely present on the surface of OCC fibers (Fig. 7, left).

Also, Wan *et al.* (2011) concluded that the fiber lumens were collapsed and the pores irreversibly closed after the pressing and drying processes. This means that recycling leads to reduced swelling capability of the recycled pulp.

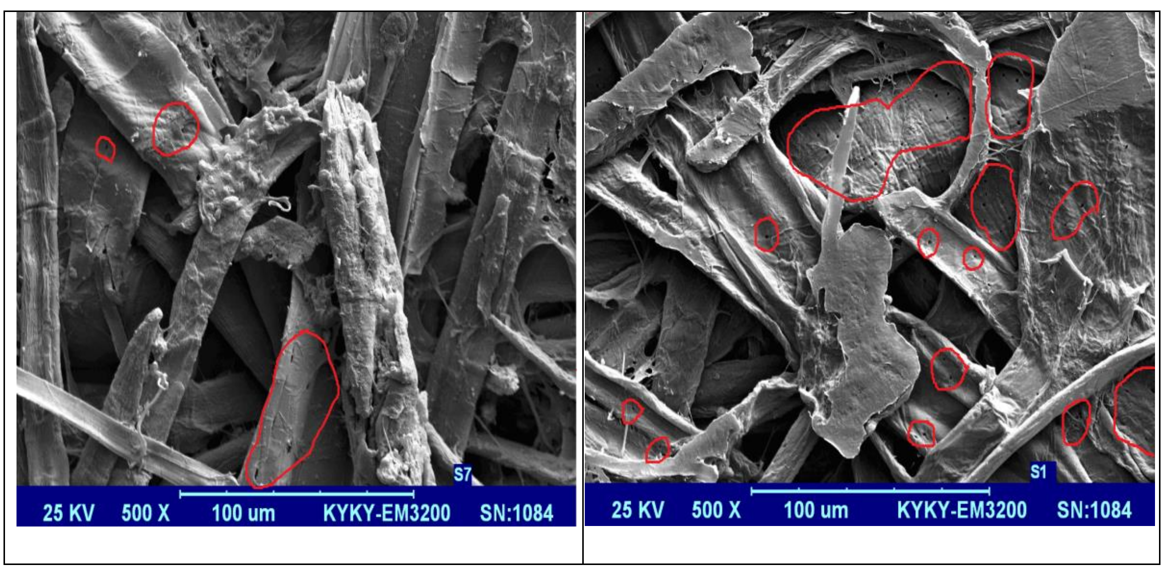

Fig. 7. Scanning electron microscope micrographs of the surface of virgin fibers (right) and recycled fibers (left); open pores of the fiber are marked in red

Finally, further research is required to improve the inter-fiber bonding potential for both virgin bagasse pulp and recycled OCC pulp in order to increase the percentage of recycled pulp in the mixture or to increase the strength of the final product.

CONCLUSIONS

1. When virgin bagasse pulp was blended at relatively low levels (10 to 30%) into recycled OCC pulp, there was no significant increase in the strength properties of the handsheets versus the control sample. But, adding 50% or more bagasse fibers had a significant effect, increasing the strength properties.
2. The relationship between apparent density and tensile strength was very strong, and the microscopic evidence showed that the bagasse fibers tended to fill up voids in the sheet.
3. Blending bagasse pulp with OCC pulp in a 70:30 ratio significantly improved the strength properties, except tear index, when compared to 100% OCC pulp; the following characteristics could be achieved: burst index 1.92 kPa•m^2/g; tensile index 32.69 N•m/g; tear index 6.22 mN•m^2/g; CMT 262 N; air resistance 48.86 s/100 mL; and double fold 240.

REFERENCES CITED

Abou-Yousef, H., El-Sakhawy, M., and Kamel, S. (2005). "Multi-stage bagasse pulping by using alkali/Caro's acid treatment," *Ind. Crop. Prod.* 21(3), 337-341.

Agnihotri, S., Dutt, D., and Tyagi, C. H. (2010). "Complete characterization of bagasse of early species of saccharum officinerum –co 89003 for pulp and paper making," *BioResources* 5(2), 1197-1214.

Azizi Mossello, A., Harun, J., Resalati, H., Ibrahim, R., Fallah Shams, S. R., and Tahir, P. Md. (2010). "New approach to use of kenaf for paper and paperboard production," *BioResources* 5(4), 2112-2122.

Barimany Aboksari, A., Azizi, M., Gasemian, A., and Mohebbi, N. (2013). "Economic assessment of producing a fluting paper using agricultural residue – A case study: Iran, Mazandaran Province," *Int. J. Sustain. Eng*. DOI: 10.1080/19397038.2012.727497

Biermann, C. J. (1996). *Handbook of Pulping and Papermaking*, Second Edition, Academic Press Ltd., London, England.

Biricik, Y., and Atik, C. (2012). "Effect of cellulase treatment of long fiber fraction on strength properties of recycled corrugated medium," *Afr. J. of Biotechnol.* 11(58), 12199-12205.

Biricik, Y., and Atik, C. (2012). "Effect of cellulase treatment of long fiber fraction on strength properties of recycled corrugated medium," *Afr. J. of Biotechnol.* 11(58), 12199-12205.

Covey, G., Rainey, T. J., and Shore, D. (2006)."The potential for bagasse pulping in Australia," *Appita J.*, 59(1), 17-22.

Dutt, D., and Tyagi, C. H. (2011). "Comparison of various eucalyptus species for their morphological, chemical, pulp and paper making characteristics," *Indian J. Chem. Technol.* 18, 145-151.

Fang, Y. P. (1977). "Kraft green liquor pulping of Douglas fir for corrugating medium," Thesis (M.S.), Oregon State University.

Freeland, S. A., and Hrutfiord, B. F. (1994)."Caustic treatment of OCC for strength improvement during recycling," *Tappi J.* 77(4), 185-191.

Garg, M., Gautam, A. K., and Singh, S. P. (2008). "Wheat straw pulp as reinforcing aid for recycled softwood pulp," *IPPTA J*. 20(2), 113-117.

Ghasemian, A., Ghaffari, M., and Ashori, A. (2011). "Strength-enhancing effect of cationic starch on mixed recycled and virgin pulps," *Carbohyd. Polym.* 87(2), 1269-1274.

Guo, W. J., Wang, Y., Huang, M. Z., Wan, J. Q., and Ma, Y. W. (2011). "An investigation of the variation of pore structure in *Eucalyptus* fiber during recycling," *BioResources* 6(2), 1029-1042.

Gurnagul, N., Page, D. H., and Seth, R. S. (1990). "Dry sheet properties of Canadian hardwood kraft pulps," *J. Pulp Pap. Sci*.16(1), 36-41.

Horn, R. A. (1978). "Morphology of pulp fiber from hardwoods and influence on paper strength by U.S. government printing office," Res. Pap. FPL-312, USDA, Forest Products Laboratory, Madison, WI, 8 pp.

Howard, R. C. (1990)." The effects of recycling on paper quality," *J. Pulp Pap. Sci*. 16(5), 143-149.

Huang, G . L., Shi, J. X., and Langrish, T. A. G. (2008). "Environmentally friendly bagasse pulping with NH_4-KOH-AQ," *J. Clean. Prod.* 16(12), 1287-1293.

Hurter, R. W. (2007). "Developments in pulp and paper manufacture from sugarcane bagasse," Symposium and Workshop May 3-4, 2007, Queensland University of Technology (QUT), Brisbane, Australia, 70 pp.

Jayme, G. (1958). "The arrangement of microfibrils in dried cellulose and the implication of these structural alteration pulp properties," in *Fundamentals of Papermaking Fibres: Transactions of the Symposium*, British Paper and Board Makers' Association, Technical Section, London, 263-270.

Kautto, J., Saukkonen, E., and Henricson, K. (2010). "Digestibility and papermaking properties of prehydrolyzed softwood chips," *BioResources* 5(4), 2502-2519.

Khakifirooz, A., Samariha, A., and Ebrahimpour Kasmani, J. (2011). "Neutral sulfite semi-chemical pulping of bagasse," *World Appl. Sci. J.* 13(1), 85-89.

Khristova, P., Kordsachia, R. P., and Karar, I., (2006). "Environmentally friendly pulping and bleaching of bagasse," *Ind. Crop Prod.* 23(2), 131-139.

Kiaei, M., Samariha A., and Ebrahimpour Kasmani, J. (2011). "Characterization of biometry and the chemical and morphological properties of fibers from bagasse, corn, sunflower, rice and rapeseed residues in Iran," *Afr. J. Agr. Res.* 6(16), 3762-3767.

Lam, H. Q., Biget, Y. L., Delmas, M., and Avignon, G. (2004). "Production of paper grade pulp from bagasse by a novel pulping process," *Appita J.* 57 (1), 26-29.

McGrattan, W. (1990). "Key characteristics of linerboard, corrugating medium, and roll stock mechanical conditions and their influence on the manufacture of corrugated products, Part 1," *Tappi J*. 73(11), 99-108.

Minor, J. L., and Atalla, R. H. (1992). "Strength loss in recycled fibers and method of restoration," *Mat. Res. Soc.* 266, 215-228.

Page, D. H. (1969). "A theory of the tensile strength of paper," *Tappi J.* 52(4), 674-681.

Perng, Y. S., Wang, E. C., Chen, Y. C., and Cheng, Y. L. (2009). "Effects of fiber morphological characteristics and refining on handsheet properties," *Taiwan J. For. Sci.* 24(2), 127-139.
Sarkhosh Rahmani, F., and Talaeipoor, M. (2011). "Study on production of fluting paper from wheat straw soda – AQ pulp and OCC pulp blends," *Iranian J. Wood Pap. Sci. Res.* 26, 387-397 (in Persian).
Wan, J., Yang, J., Ma Y., and Wang, Y. (2011). "Effects of pulp preparation and papermaking processes on the properties of OCC fibers," *BioResources* 6(2), 1615-1630.
Wang, J., Zhou, X., and Ma, J. (2012). "Preparation and characteristics of a paper-based ultrafilteration membrane," *BioResources* 7(1), 545-553.
Wistara, N., and Hidayah, H. N. (2010)."Virgin bamboo pulp substitution improved strength properties of OCC pulp," *Jurnal Ilmu dan Teknilogi Hasil Hutan* 3(1), 14-18.
Zanuttini, M. A. (1997). "Factors determining the quality of bagasse mechanical pulps," *Cellulose Chem. Technol.* 31(5-6), 381-390.
Zanuttini, M. A., Marzocchi, V. A., and Mocchiutti P. (2009)."Alkaline peroxide treatment for improving the papermaking properties of recycled unbleached softwood kraft pulps," *Cellulose Chem. Technol*. 43 (1-3), 65-69.

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