APPLICATION OF NSSC PULPING TO SUGARCANE BAGASSE

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The NSSC pulping process was investigated to produce pulp from bagasse for corrugating board manufacture. The chemical contents including cellulose, lignin, ash, and extractives soluble in alcohol-acetone measured 55.75, 20.5, 1.85, and 3.25, respectively. The average fiber length, fiber diameter, lumen width, and cell wall thickness of bagasse were 1.59 mm, 20.96, 9.72, and 5.64 µm, respectively. The optimum conditions, with a yield of 74.95%, were achieved using 20 percent chemicals on the basis of sodium oxide, cooking temperature of 170 °C, and cooking time of 30 minutes. Pulp was refined to freeness 345 and 433 mL CSF according to Canadian standards. 127 g m^{-2} handsheets from both pulps were made and strength properties measured. Statistical analysis of results indicated that paper derived from freeness 345 and 433 mL CSF had better strength properties in all indices in comparison with NSSC pulp from hardwoods produced at Mazandaran Pulp and Paper factory, Iran.

Keywords: Bagasse; Fiber length; NSSC pulp; Strength properties; Yield

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INTRODUCTION

Sugarcane bagasse is a plentiful lignocellulosic waste typically found in tropical countries that process sugarcane, such as Brazil, India, Cuba, and Iran.

The sugarcane stalk consists of two parts, an inner pith containing most of the sucrose and an outer rind with lignocellulosic fibers. During sugar processing, the sugarcane stalk is crushed to extract sucrose (Boopathy 2004). This procedure yields a large volume of residue, the bagasse, which contains both crushed rind and pith fibers. Bagasse, the sugarcane residue after sugar extraction, is one of the most available papermaking lignocellulosic fiber resources in some developing countries, e.g., Iran. Approximately 4.3 million tons of bagasse is produced annually in Iran, and the production is mainly centered in the southwestern province of Khuzestan (Najafi et al. 2009). About 54 million tons of bagasse is produced annually throughout the world. In general, sugar factories generate approximately 270 kg of bagasse (50% moisture) per metric ton of sugarcane (Xu et al. 2006). These agricultural residues represent an abundant, inexpensive, and readily available source of renewable lignocellulosic biomass (Sun et al. 2004). The chemical compositions of pure bagasse fiber bundles are cellulose (52.42%), lignin (21.69%), hemicelluloses (25.8%), ash (2.73%), and ethanol/dichloro methane extract (1.66%) (Rezayati-Charani and Mohammadi-Rovshandeh 2005).

This large increase in nonwood pulp production has motivated research activities worldwide, and various research groups have initiated works to improve nonwood pulping. Such research covers a wide range from conventional soda pulping of bagasse and cereal straw to reeds and bamboo to even date palm tree branches and rachises (Khristova et al. 2005). Various alternative pulping processes including neutral sulfite pulping of wheat straw (Ali et al. 1991), and soda/AQ, alkaline sulfite/AQ, and ASAM pulping of date palm residues (Khristova et al. 2005) have been investigated. Alkaline sulfate/AQ pulping and totally chlorine free bleaching were applied on wheat straw, rice straw, and bagasse to develop an alternative pulping for these materials (Hedjazi et al. 2008a,b; 2009). Other pulping processes have been studied to increase the pulping yield. Wheat straw alkaline peroxide mechanical pulping (APMP) (Pan and Leary 2002), APMP pulping of bagasse and kenaf (Xu and Rao 2001), and chemi-mechanical pulping of kenaf (Law et al., 2003) are recent examples. The properties of bagasse for NSSC pulping production have never been explored in the literature. Therefore, in this study the biometrical properties, chemical composition, and NSSC pulping properties of bagasse were investigated to evaluate the potential utilization of bagasse fibers in pulp and paper production.

EXPERIMENTAL

Material

The depithed bagasse used in this study was collected from a local pulp and paper mill (Pars Paper Co. Haft Tapeh. Iran).

Methods

Measurement of fiber biometry characteristics

The pieces of bagasse were defibrated using the technique developed by Franklin (1954), and then the fiber length, fiber diameter, and lumen width were measured with a microscope equipped with a Leica Image Analysis System (Quantimeta 100+). The fiber wall thickness was calculated as a difference of fiber diameter and lumen width divided in half. For dimensions of 120 fibers were randomly measured. From these data, the average fiber dimensions were calculated and then the following derived indexes were determined:

$$\text{Runkel ratio} = 2 \times (\text{Wall thickness}/\text{Lumen width}) \quad (1)$$

$$\text{Flexibility ratio} = (\text{Lumen width of fiber}/\text{Diameter of fiber}) \times 100 \quad (2)$$

$$\text{Slenderness ratio} = (\text{Length of fiber}/\text{Diameter of fiber}) \quad (3)$$

Chemical composition

The lignin, ash, and ethanol/acetone extractable of bagasse were determined according to TAPPI Test Methods. The cellulose content of bagasse was determined according to the nitric acid (Rowell and Young 1997) method. All measurements were repeated three times.

The proportions of the chemical constituent in the bagasse fibers were determined according to TAPPI Test Methods. Lignin, alpha-cellulose, ash, and ethanol/acetone extractable of bagasse fiber were determined according to TAPPI T222 om-97, T203 cm-99, T267 om-85, and T207 om-97, respectively. The cellulose content of bagasse was determined according to the nitric acid (Rowell and Young 1997) method. Holocellulose (sum of the cellulose and hemicelluloses) was determined following the procedure of Wise and Karl (1962). All measurements were repeated three times.

Experimental cooking

Wet depithed bagasse was transferred to the Research laboratory Center of Mazandaran Pulp and Paper factory. Neutral Sulfite Semi Chemical pulping (NSSC), using an experimental rotating and cut off digester (HATTO) with 10 liter capacity and 500 grams of depithed bagasse, was used in each trial. Pulping time was measured after reaching pulping temperature. After four experimental cooks, NSSC Pulp yielded 74.95 percent. Results of bagasse cooking carried out using white liqueur of Mazandaran Pulp and Paper Factory including sodium sulfite (Na_2SO_3) and sodium carbonate (Na_2CO_3) at a 2.77 to 1 weight ratio sulfite to carbonate. Optimum cooking conditions are shown in Table 1.

Table 1. Optimum Conditions for Producing NSSC Pulp from Bagasse

Cooking condition	NSSC pulping	Cooking condition	NSSC pulping
Chemical charge	Sodium sulfite (Na_2SO_3) and bicarbonate ($NaHCo_3$)	Chemical charge (%)	10 and 20
Liquor-to-Bagasse ratio	10:1	Time of Impregnation (min)	30
Cooking temperature (°C)	170	Cooking time at maximum temperature (min)	30 and 40

Pulp refining and handsheet making

NSSC pulp from bagasse was refined using a laboratory PFI Mill according to CPPA-C.7 standard for 2600 and 5500 revolutions until NSSC bagasse pulp with primary freeness of 710 mL CSF reached a final freeness of 433 and 345 mL CSF. Factory NSSC pulp was refined at 3800 revolutions to get to a freeness 414 mL CSF and imported long-fiber pulp refined for mixing with factory pulp to attain a freeness of 520 with a PFI Mill. According to the TAPPI T 205 om-88 test method, eight handsheet papers with basis weight 127 gm^{-2} prepared from NSSC bagasse pulp and pulp from Mazandaran Pulp and paper factory were selected as control samples.

The paper sheets were conditioned at 23 ºC and 50% R.H. for 24 hours. Then, the basis weight, caliper, ring crush test, burst index, tear index, tensile index, breaking length, and stiffness of paper sheets were determined according to TAPPI; T401-om 88, T411-om 89, T 818 om-87, T 403 om-91, SCAN P11:73, and T494 om-88 test methods, respectively. The reported results represent the average values of 5 handsheets. Finally, in order to compare the results of paper strength test, a two-way analysis of variance test and Duncan's multiple range test using SPSS software were performed.

RESULTS AND DISCUSSION

Fiber Dimensions and Derived Indexes

The fiber dimensions and biometrical coefficient of bagasse are summarized in Table 2.

The results show that the bagasse contained fibers with a mean length of 1.59 mm. The bagasse fibers are in the range of hardwoods, and longer than cotton stalks (0.83 mm) (Ververis et al. 2004), and date palm tree rachis (1.13 mm) (Khristov et al. 2005), and shorter than wheat straw (1.73 mm) (Mackean and Jacobs 1997). On the other hand, cell wall thickness of bagasse fibers is thicker than those of aspen (1.93 µm) (Law and Jiang 2001) and cotton stalks (3.40 µm) (Ververis et al. 2004). More cell wall thickness of fibers causes more flexibility of fibers in pulp refining process. Increase of cell wall thickness has a direct effect on strength properties of fibers. Therefore it is expected that with the resulting paper strength, properties can be met after refining. Consequently, the calculated Runkel ratio for bagasse fibers (1.16) is higher than that of cotton stalks (0.84), aspen (0.23), and date palm rachis (0.8) fibers. The slenderness ratio of bagasse fibers is 75.85 and is higher than that of cotton stalks (42.35), and aspen (46.15) fibers. Generally, the acceptable value for slenderness ratio of papermaking is more than 33, respectively (Xu et al. 2006). But the flexibility coefficient of bagasse fibers is less than both cotton stalks (65.31), and aspen (81.44). According to flexibility ratio there are 4 groups of fibers (Bektas et al., 1999): 1) High elastic fibers having elasticity coefficient greater than 75. 2) Elastic fibers having elasticity ratio between 50-75. 3) Rigid fibers having elasticity ratio between 30-50. 4) Highly rigid fibers having elasticity ratio less than 30. According to this classification, the flexibility coefficient of bagasse fibers is 46.37, so it is included in the rigid fibers group.

Table 2. Fiber Dimensions and Biometrical Coefficient of Bagasse.

Fiber dimensions	Value %
Length	1.59 (mm)
Diameter	20.96 (µm)
Lumen width	9.72 (µm)
Cell wall thickness	5.63 (µm)
Runkel ratio	1.16
Slenderness ratio	75.85
Flexibility ratio	46.37

Chemical Characteristics

The percentage of cellulose, holocellulose, alpha-cellulose, lignin, extractive soluble in alcohol-acetone, and ash are summarized in Table 3.

The cellulose content of bagasse was found to be 55.81%, which is satisfactory for pulp production (close to or above 40%). The result obtained for the cellulose content of bagasse was close to an earlier finding (52.42%) (Rezayati-Charani and Mohammadi-

Rovshandeh 2005), whereas the cellulose content of bagasse was higher than that of rice straw (41.20%) (Rodriguez et al. 2008), and wheat straw (38.20%) (Deniz et al. 2004). The holocellulose content of bagasse is higher than that of rice straw (60.70%) (Rodriguez et al. 2008) and similar to *hibiscus cannabinus* Bast (73.2%) (Udohitinah and Oluwadare 2011). The alpha-cellulose content of bagasse is 47.4%. These values are quite high. According to Nieschlag et al. (1960) plant materials with alpha-cellulose of 34% and above are characterized to be suitable for pulp and paper manufacture. The lignin content of bagasse was found to be lower than that of rice straw (21.90%), and Egyptian cotton stalks (22.50%) (Ali et al. 2001). The organic solvent extractive of bagasse was found to be higher than those of rice straw (0.56%) and aspen (2.50%). The organic solvent extractive was lower than that of wheat straw (7.80%). The ash content of bagasse was also low.

Table 3. Chemical Composition of Bagasse (% on OD basis)

Component	Value %
Cellulose	55.81
Holocelluloses	74.77
Alpha-cellulose	47.4
Lignin	20.35
Extractives soluble in alcohol - acetone	3.15
Ash content	1.74

Pulping Process

First, experimental cooking with 10 percent chemicals (oven dry weight), cooking time of 30 minutes, temperature of 170 °C, and a liquor-to-bagasse ratio 10 to 1 was performed, but the results were not desirable. According to the derived preliminary information and to select optimum cooking conditions, an intense condition of bagasse cooking with usage of 20 percent chemicals was carried out. After comparing the results of experimental cooking data, optimum cooking condition were selected. Selected pulp from optimum condition had lighter color and felt better to the touch. Pulp was separated using a laboratory defibrator.

According to the test results, the best cooking conditions for producing neutral sulfite semi-chemical pulping of bagasse were with a temperature of 170 °C, cooking time of 30 minutes, 20 percent of chemicals, and a liquor-to-bagasse ratio 10 to 1. This cooking condition led to 74.95 percent of pulp yield.

Pulp Refining

Initial freeness of bagasse NSSC pulp due to non-uniform distribution of fibers and rapid drainage was somewhat high, and it was not considered to be well suited for papermaking. Therefore, to improve fiber distribution and water drainage control, and ultimately to improve paper strength properties, pulp and fibers were refined with a laboratory PFI Mill.

Because there was no significant difference in the most properties of two bagasse pulp with freeness 345 and 433 mL CSF, and to improve the ability of pulp drainage on papermaking machine, pulp with a freeness of 433 mL CSF is recommended as compared with NSSC Pulp from the factory (Mazandaran Pulp and Paper) The higher-freeness bagasse NSSC pulp was also judged to have more suitable properties.

Statistical analysis of paper strength properties showed that paper made from bagasse pulps with freeness 345 and 433 mL CSF had significantly better strength properties in all strength indices than the paper made in Mazandaran Pulp and Paper factory.

Handsheet Preparation

Since the factory produces 127 gm^{-2} fluting paper, for comparative evaluation of pulps produced in factory and laboratory from bagasse, 127 gm^{-2} handsheet papers consisting of 95% factory NSSC pulp mixed with 5% imported long-fibers were prepared in the laboratory, and then strength properties were evaluated and compared.

Physical and Mechanical Properties of Handsheet Papers

Statistical analysis of NSSC pulp from factory and unmixed bagasse with freeness 345 and 433 mL CSF showed that approximately with equal basis weight, the unmixed bagasse pulp with freeness 345 mL CSF and 433 mL CSF had less thickness than the factory pulp. The difference is attributed to a greater relative bonded area between fibers in bagasse pulp (Fig. 1).

The highest tensile strength index and ring crush test results were achieved with NSSC of bagasse pulp having a freeness of 345 mL CSF, and the lowest value was observed from fluting paper from the factory’s NSSC pulp. From a statistical point of view and 99 percent confidence level, paper made with freeness 345 or 433 mL CSF comprised a single group, and there was no statistically significant difference between them. Tensile strength index of paper made from factory NSSC pulp comprised a second group and had a significant difference with the other group (Figs. 2 and 5).

Analysis of resistance characteristics including breaking length, stiffness, tear strength index, and burst strength index of bagasse papers with freeness 345 mL CSF were significantly more than papers from NSSC pulp of factory. Furthermore, the resistance characteristics of pulp with freeness 345 mL CSF were significantly more than papers made from pulp with freeness 433 mL CSF (Figs. 3, 4, 6, and 7).

Papers from bagasse pulp with freeness 433 mL CSF had completely preferable strength parameters as compared with papers produced from factory pulp. Considering the most important strength characteristics of fluting paper, including ring crush test, tensile strength index, and stiffness, as well as the lesser importance of burst strength index, unmixed bagasse pulp with a freeness of either 345 or 433 mL CSF can be used for fluting paper. Since the pulp with freeness 345 and 433 mL CSF from the viewpoint of the strength characteristics ring crush test and tensile strength index had no significant difference and to improve drainage and papermaking machine speed for fluting paper production, pulp with freeness 433 mL CSF was judged to be preferable.

Strength properties compared with other lignocellulosic resources have shown that the ring crush test of bagasse is less than sunflower stem (1.94 KN m^{-1}) (Khassipour 2002; Roodi 2002) but it's stiffness is more than sunflower stem (685.5 KN m^{-1}). The tensile strength index of bagasse (46.69 Nm g^{-1}) was more than Mazandaran paper made from bagasse (46.69 Nm g^{-1}) and paper made from sunflower stem (41.29 Nm g^{-1}). Tear strength index of bagasse was less than bagasse from Mazandaran (6.5 mN m^2 g^{-1}) and more than sunflower (6.06 mN m^2 g^{-1}). Burst index of bagasse was more than Mazandaran paper (3.07 $KPam^2$ g^{-1}) and sunflower stem (2.017 $KPam^2$ g^{-1}). Breaking length of bagasse was more than Mazandaran paper (5.06 km) and sunflower stem (4.21km).

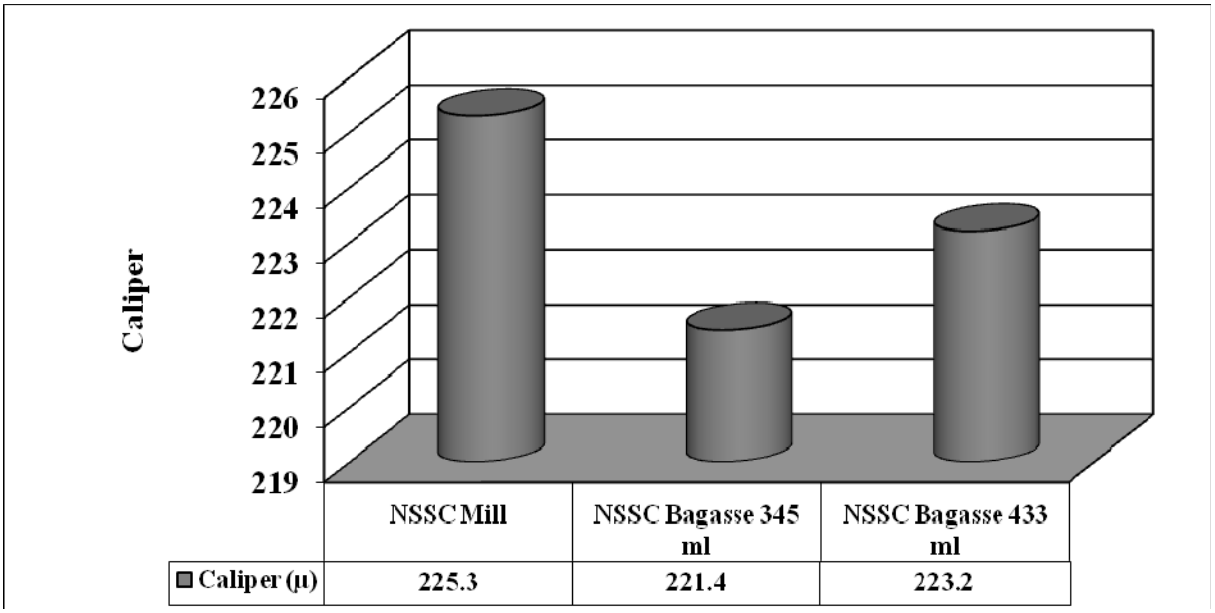

Fig. 1. Comparison of caliper between papers produced from bagasse NSSC pulp and factory NSSC pulp

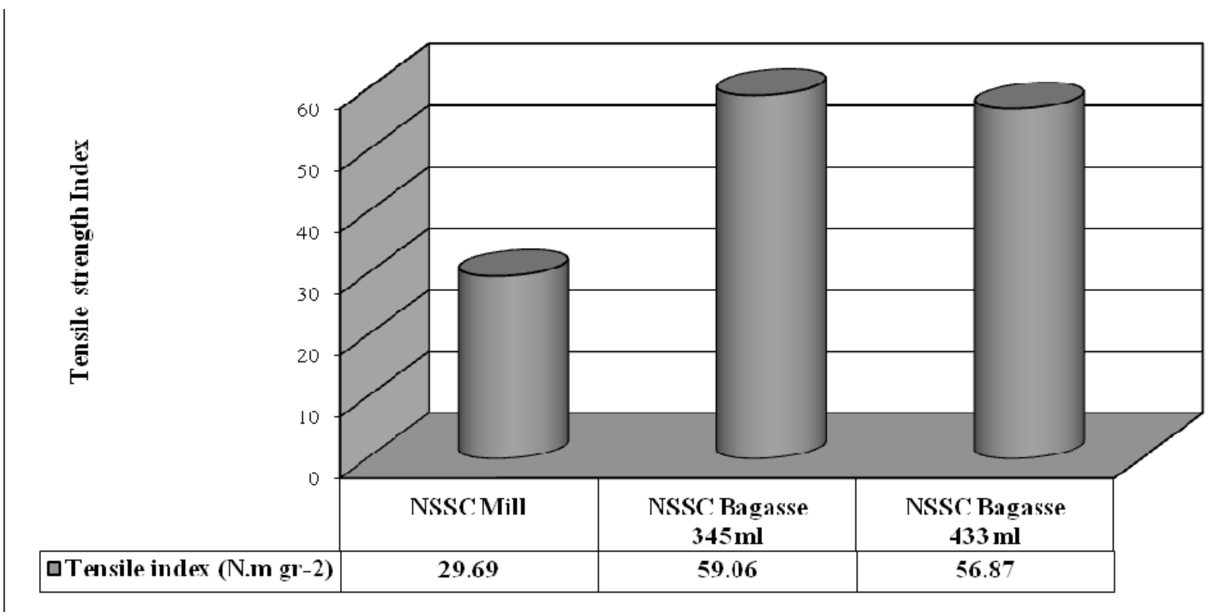

Fig. 2. Comparison of tensile strength index between papers produced from bagasse NSSC pulp and factory NSSC pulp

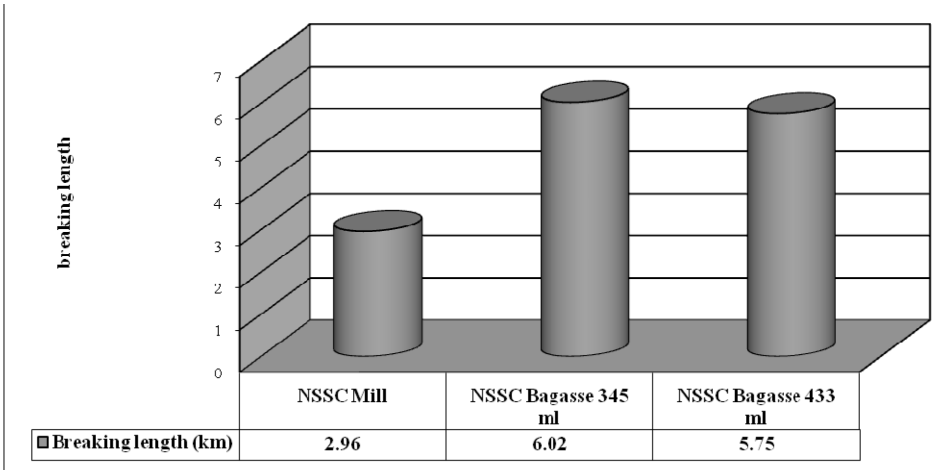

Fig. 3. Comparison of breaking length between papers produced from bagasse NSSC pulp and factory NSSC pulp

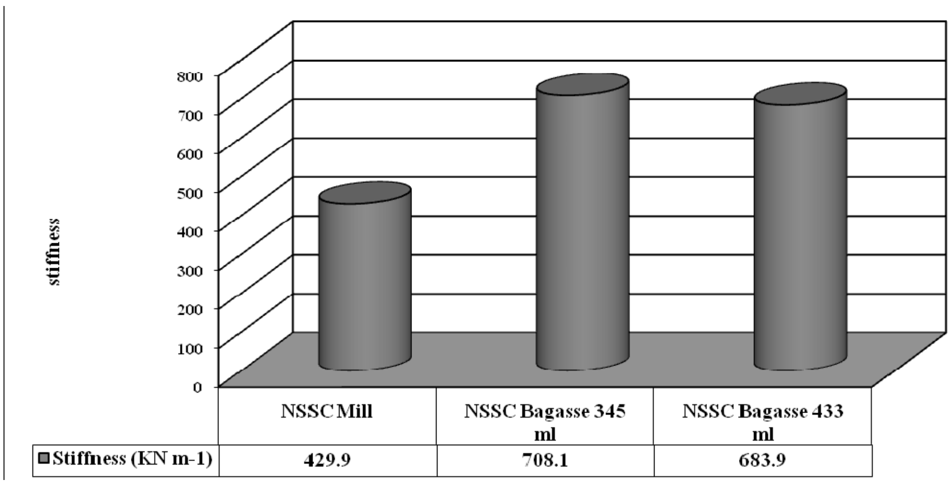

Fig. 4. Comparison of stiffness between papers produced from bagasse NSSC pulp and factory NSSC pulp

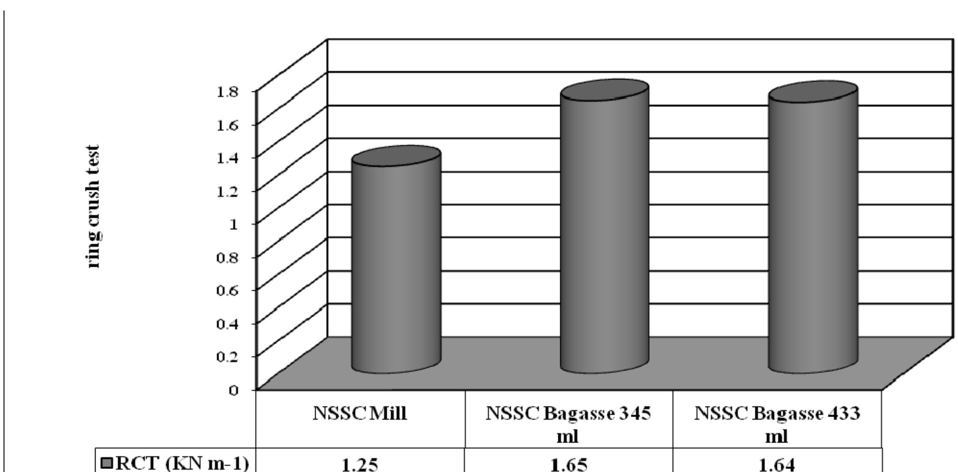

Fig. 5. Comparison of ring crush test between papers produced from bagasse NSSC pulp and factory NSSC pulp

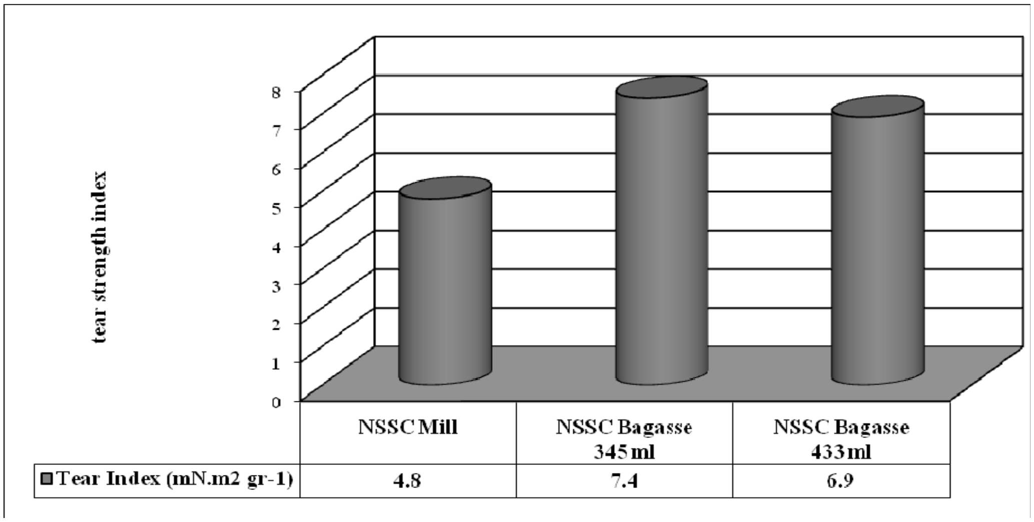

Fig. 6. Comparison of tear strength index between papers produced from bagasse NSSC pulp and factory NSSC pulp

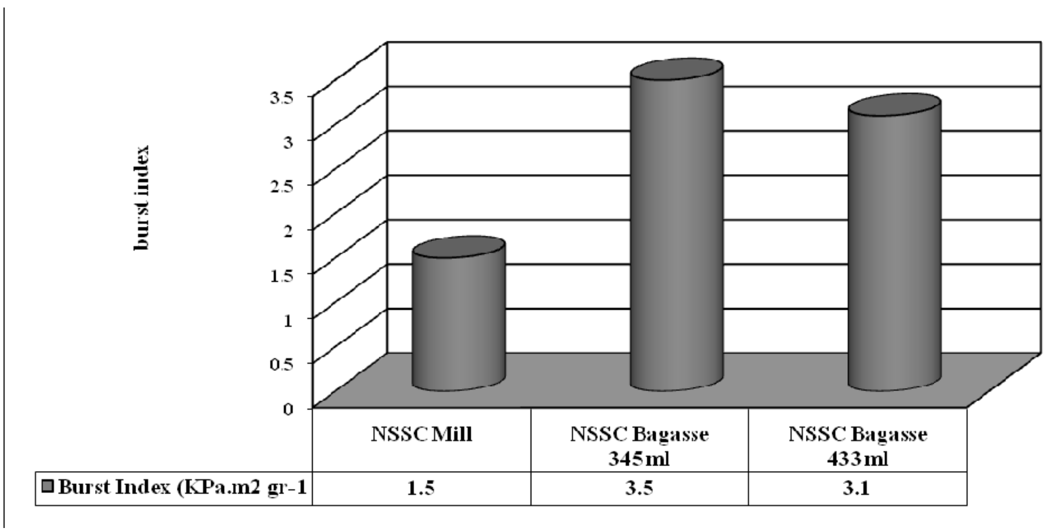

Fig .7. Comparison of burst index between papers produced from bagasse NSSC pulp and factory NSSC pulp

CONCLUSIONS

1. The results of a biometrical study showed that bagasse contained fibers with similar average biometrical properties to the hardwood fibers, except that the cell wall of bagasse was thicker.
2. Chemical compositional analysis showed that the lignin content of bagasse was lower than other nonwood papermaking fiber resources. The holocellulose content of bagasse is higher than other nonwood papermaking resources. It was found that the bagasse contained low amounts of ash.

3. The strength properties of refined bagasse NSSC pulp were determined to be comparable with those of pulps from hardwoods and typical nonwood papermaking raw materials.
4. The overall results showed that bagasse has a promising potential to be used in combination with softwood or hardwood pulps in papermaking.

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Article submitted: May 12, 2011; Peer review completed: June 28, 2011; Revised version received and accepted: July 16, 2011; Published: July 18, 2011.