

Mechanical properties of beating pulp and paper from rice straw

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Abstract

This study was carried out to investigate the effect of beating on rice straw pulp and paper properties. The rice straw pulps were produced from pulping process using chemi-mechanical pulping (CMP) method and then were beaten. Pulp produced with and without beating was evaluated for apparent density and freeness. The beaten pulp showed significantly better apparent density and freeness than unbeaten pulp. The apparent density of beaten and unbeaten pulps was 0.74 g/cm³ and 0.69 g/cm³ respectively, while the freeness of beaten and unbeaten pulps was 250 ml and 415 ml respectively. The paper from beaten pulp showed significantly better mechanical properties, whereby the tensile index is at 79.57 Nm/g, burst index at 5.70 kPa.m², tear index at 4.17 mNm²/g and folding endurance at 508, whereas, the unbeaten paper is at 67.28 Nm/g, 4.98 kPa.m², 3.28 mNm²/g and 195 respectively. The optical behaviour such as opacity and brightness of paper from beaten and unbeaten pulps showed no significant values. The opacity and brightness of paper for beaten pulp were 99.81% and 32.44% respectively, while the paper using unbeaten pulp were 99.88% for opacity and 33.58% for brightness.

Keywords: rice straw, pulp, beating, chemi-mechanical, paper properties

Introduction

Rice is a grass and belongs to the genus *Oryza* (meaning oriental). It is grown in a wide range of environment, from the equatorial tropics to sub-tropical mid-latitudes, from lowland paddy fields to high altitude terraces, and from swamps to upland rice fields. Among the by-products of rice industry are straw and husk. Straw is removed from the field, burned in situ, piled or spread in the field, incorporated in the soil, or used as mulch for the following crop (Lim et al. 2012).

Straw as an agricultural waste biomass could be used as an alternative source

of lignocellulosic to substitute forest for reduction of greenhouse gas emission as well as to avoid local pollution problems from open burning. Straw as lignocellulosic materials can be used by many industries and converted into many value added products such as pulp and paper. Rice straw has been used as a source of pulp in Egypt for making commercial grade paper and in China for high grade artistic paper. Paper made in Egypt is from a mixture of rice straw pulp and a high grade pulp from wood imported from Scandinavia (Mudit 1998).

Malaysia produces more than 2.0 million tonnes of rice. The straw production

is about 45 – 50% of the total of rice cultivation (MADA 2010). In 2000, total production of straw from 2 periods of paddy cultivation was 2,616,600 tonnes. The amount increased to 3,012,571 tonnes in 2010 and 3,177,022 tonnes in 2012 (DOA 2013).

Straw can be utilised for pulp and paper-based product. It is feasible to be pulped since it contains 13.5% lignin (Kiran et al. 2000). The texture of straw is finer and more attractive as compared to the other local materials such as banana trunk, kantan trunk, mengkerai trunk and pandan leaves (Rosmiza 2012).

Chemi-mechanical pulp (CMP) can be obtained by pretreating the plant materials with sodium carbonate, sodium hydroxide, sodium sulfite and other chemicals prior to refining with refiner mechanical machines. The chemical treatment is much less vigorous (lower temperature, shorter time, less extreme pH) than the chemical pulping process since the goal is to make the fibres easier to refine and not to remove lignin as in a fully chemical process (Wikipedia 2013).

In general, pulp refining or beating has two simultaneous effects on fibres, it opens each fibre and the fibre layers, thus increases its elasticity and flexibility (Kure 1997; Molin 1995). In fact, a refinement is a type of mechanical treatment on fibre. The influence of shear, tensile and compressive forces during beating had changed the systems in the fibres (Jang et al. 1996). The refining process of fibres can change its properties as follows:

- 1) Fibres could be enlarged (Molin 1995)
- 2) More fibre flexibility
- 3) Fibrillation of the secondary wall, and
- 4) Slits in fibres and increase in fine particles with the objective of a desirable formation of paper sheets (Mirshokraei 1995).

Losing initial walls fibres in refining, creates a better situation for flexibility and connection (Molin et al. 2004).

Beating is the most important physical treatment carried out on pulp before papermaking. It highly affects the physical properties of the prepared paper sheets. It increases the area of contact between the fibres by increasing their surface through fibrillation and its flexibility. It was also found that beating improves the tearing strength, burst, tensile and folding properties (Raymond and Rowell 1986), thus improves the runnability-related strength properties of paper. Typically, the aim is to increase the surfaces and bonding ability of fibres so that most of the paper strength properties will improve. However, certain paper properties, e.g. optical parameters, decrease during beating.

The objective of this study was to investigate the effect of beating on the performance of pulp and paper properties of rice straw. At the end of the study, we can observe the effect of beating on the properties of pulp and paper performances.

Materials and methods

Rice straw was taken from MARDI Tanjung Karang, Selangor. A long strand of rice straw was manually cut to a size of 10 – 30 mm using a knife.

One kg (oven-dry weight) of rice straw was soaked for 18 h in a 5% solution of sodium hydroxide (NaOH) at room temperature before being heated to a temperature of 60 °C in a rotary digester for 1 h. The liquor to fibre ratio was 8:1. After CMP pulping, the straw was washed to remove all NaOH from the surface. The pre-treated straw was fed into a 12-inch single disc atmospheric laboratory refiner (Sprout Waldron) in a two-stage operation. The primary stage was operated at a load between 18 and 20 amperes at an inlet consistency of 10% and the plate (D2A507, Sprout Waldron) clearance was set at 0.89 mm. The collected stocks were refined in a secondary stage that operates with an inlet consistency of 7%, and with the refiner plate clearance set at 0.13 mm. The pulp obtained was thoroughly washed and screened by

the Sommerville fractionator with a screen plate of 0.20 mm slits (Syahira and Rushdan 2012).

The screened pulp was used for the beating process. This process was done using PFI mill at 1000 revolutions according to TAPPI Standard T 248 sp-08 (TAPPI 2008). Both unbeaten and beaten pulp were tested for their pulp properties which include freeness, apparent density and yields.

Pulp and paper testing

This test method for freeness measurement describes a procedure for measurement of the drainage rate by using the Canadian Freeness Tester according to TAPPI T 227 om-99 (TAPPI 1999).

Paper or handsheets were made according to TAPPI T 205 om-88 (TAPPI 1988a). The paper was made by mixing the pulp with water in a British handsheet former, put on the screen and pressed at 345 kPa (50 psi) for 5 min and dried in the stainless steel stacker for 24 h or longer. The handsheets were cut and tested according to TAPPI T 220 om-88 (TAPPI 1988b). All handsheet properties were tested in a controlled temperature and humidity condition as stipulated in TAPPI T 402 om-93 (TAPPI 1993). The paper properties were analysed as follows:

The apparent density is the weight of paper per unit area. This can be expressed as the weight in grams per square meter (GSM or g/m^2). The procedure was according to TAPPI Standard T 410 om-98 (TAPPI 1998a).

To test the bursting strength, a burst tester was used according to TAPPI Standard T 403 om-97 (TAPPI 1997). The pressure at rupture (B.kPa) was read from the instrument and burst index was calculated using the following formula (TAPPI 1997):

$$\text{Burst index, kPa.m}^2 / \text{g} = \frac{B}{G}$$

B = Bursting strength, kPa

G = Grammage, g/m^2

The folding test was done according to TAPPI T 511 om-96 (TAPPI 1996) folding machine model PMP-6BAR.

The standardised 4-ply Elmendorf (out-of-plane) tear has been used in the industry for many decades according to TAPPI Standard T 414 om-98 (TAPPI 1998b). This method uses a L and W Tearing Tester to measure the force required to tear multiple plies of paper, perpendicular to the plane of the paper, through a specified distance, after the tear has been initiated by a standard cut. The calculation of the tear index was as follows (TAPPI 1998b):

$$\text{Tear index, Nm}^2 / \text{g} = \frac{T_e}{G}$$

T_e = Tear strength, mN

G = Grammage, g/m^2

The tensile properties of the paper are tested with a testing machine that provides a constant rate of elongation, as specified in the TAPPI Standard T 494 om-01 (TAPPI 2001b). Each specimen for tensile strength testing was clamped in the jaws of the tensile test instrument and the automatic test sequence started. The tensile strength data were displayed automatically by the instrument. Tensile index was calculated using the following formula (TAPPI 2001b):

$$\text{Tensile index, Nm/g} = \frac{T \times 1000}{G}$$

T = Tensile strength, N

G = Grammage, g/m

Opacity is the ratio measurement of the reflected light from each paper covered by a black cover with 5% reflected light in comparison with the specimen covered by a bulky paper. Opacity is measured by the Spectrophotometer Color Touch 2 (Model ISO, Technidyne Corporation USA) according to TAPPI Standard T 425 om-01 method (TAPPI 2001a). The opacity value is calculated in percentage (TAPPI 2001a).

Brightness is the term used in the industry to evaluate the value factor of

reflected blue light on the 457 nm wave. The Spectrophotometer Color Touch 2 was used to measure brightness according to TAPPI Standard T 452 om-02 (TAPPI 2002).

Experimental design and statistical analysis

A completely randomised design (CRD) was used in this experiments. All the data were analysed using Statistical Analysis Software (SAS 9.1) to study the differences between unbeaten and beaten pulp and paper properties from rice straw. The differences among the means were analysed according to Duncan Multiple Range Test at $p < 0.05$ level.

Results and discussion

Table 1 shows the freeness, grammage, apparent density as well as yield of unbeaten and beaten pulp of rice straw. There was a significant dropped of 39.75% in freeness, from 415 ml of unbeaten pulp to 250 ml of beaten pulp of rice straw. Freeness decreased after the beating could be due to the increase in pulp wetness, fibre shortening and fines production. Water will leave the unbeaten fibres very fast during drainage on the wire mesh causing these fibres unable to produce good and homogen fibres web. If the stock contains long fibres (4 – 5 mm), these fibres will easily form flocs before reaching the wire mesh. The paper produced will

exhibit poor formation due to flocculation of fibres. Fibres without fibrillation property and low flexibility tend to have poor wet-web strength, thus the paper will have low strength, high porosity, less bonding and poor formation. Beating improves the percentage of fine in fibres, thus reducing the freeness value (Samariha 2011).

The apparent density of beaten pulp significantly increases as shown in Table 1. Fibre flexibility and the relative bonding area can be determined indirectly by the paper apparent density. Apparent density is one of the most significant properties of paper. It influences almost all mechanical, physical and electrical properties. As apparent density increased, burst index and tensile index also increased (Rushdan 2007). The apparent density of rice straw pulp increased with beating (Ibrahem et al. 1989). The yields of unbeaten and beaten of rice straw are at 36%.

Table 2 shows the paper of beaten rice straw pulp has significant higher tensile index of 79.57 Nm/g compared with the unbeaten pulp of rice straw which is 67.28 Nm/g. This is because tensile strength is not only dependent on the strength of individual fibres, but is also closely related to the strength of fibre-to-fibre bonds. The increases of tensile by beating are closely related to the fibre-to-fibre bonding ability

Table 1. Rice straw pulp properties

Type of pulping	Freeness (ml)	Grammage (g/m ²)	Apparent density (g/cm ³)	Yield (%)
Unbeaten pulp	415a	61.08a	0.69a	36
Beaten pulp	250b	71.77b	0.74b	36

Means with the same letter within the same column are not significantly different at 5% level of significance

Table 2. Strength and optical properties of rice straw paper

Type of pulping	Tensile index (Nm/g)	Burst index (kPa.m ²)	Folding	Tear Index (Nm ² /g)	Opacity (%)	Brightness (%)
Unbeaten paper	67.28a	4.98a	195a	4.17a	99.88a	33.58a
Beaten paper	79.57b	5.70b	508b	3.28b	99.81a	32.44a

Means with the same letter within the same column are not significantly different at 5% level of significance

due to the creation of possible portion of hydrogen bonding which has much more accessible hydroxyl groups (Kim and Jo 2000). The main factors affecting the tensile index of paper were the strength of fibre combination and the average fibre length. Beating produced many tiny fibres in the pulp, which could fill in the space gaps among the long fibres, thus increases the number of hydrogen bonds and improves fibre combination. The tiny fibres played a bridge role in the paper and contributed to its network structure (Gao et al. 2011).

Burst index of paper of beaten pulp gave significant higher results at 5.70 kPa.m² than the unbeaten pulp at 4.98 kPa.m². It could be the factor of apparent density, whereby beaten pulp produced higher burst index than unbeaten pulp. The beating process might enhance the combination among fibres. The density of the fibre determines its flexibility, which in turn influences the extent of bonding within a sheet (Paavilainen 1989).

Table 2 shows the tear index paper of rice straw beaten pulp of 4.17 mNm²/g, which is significantly better than an unbeaten pulp of 3.28 mNm²/g. Tear index depends on individual fibre strength and on interfibre bonding. It also depends on the lateral bonds between cellulose fibres in paper sheets. These bonds are mostly hydrogen bonds between the lateral cellulose chains (Amal and Samar 2012). As it is known, tearing resistance depends on three factors: total number of fibres participating in the sheet rupture, fibre length and number, and strength of the fibre to fibre bond. Increased beating affects these factors adversely specially the fibre to fibre bonding (Ibrahim et al. 1989).

Folding endurance for paper from beaten pulp was 508, and it was found statistically higher than the beaten pulp which was 195 (Table 2). The process of beating enhanced the folding endurance due to the improvement of fibre bonding. This can be explained by considering that folding is a modified tensile strength, but

the results might be greatly affected by the flexing ability of the paper (Ibrahim et al. 1989). Beaten pulp produced no different percentage of brightness (32.44%) as compared to the unbeaten (33.58%) (Table 2). The same trend of results of opacity also demonstrated no difference among beaten (99.81%) and unbeaten paper (99.88%).

Conclusion

This study has shown that rice straw can be successfully pulped and beaten. Beating on the rice straw pulps performed better apparent density and freeness. Beaten paper demonstrated significantly better tensile index, tear index, burst index and folding properties than the unbeaten paper, but produced equal in brightness and opacity. The beating process increased pulp wetness, fibre shortening, fines production and improved percentage of fine in fibres, and therefore changed the properties of mechanical in a better performance as well as in an apparent density and freeness.

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Abstrak

Kajian ini telah dilakukan ke atas pengaruh kesan pemukulan bagi sifat-sifat pulpa dan kertas daripada jerami padi. Pulpa jerami padi dihasilkan melalui kaedah pemulpaan kimia-mekanikal dan juga pemukulan. Pulpa yang dipukul dan tidak dipukul diuji sifat-sifat ketumpatan *apparent* dan kebolehlaluan. Pulpa terpukul memperlihatkan kelebihan yang signifikan bagi ketumpatan *apparent* dan kebolehlaluan. Ketumpatan *apparent* pulpa terpukul dan tidak terpukul masing-masing adalah 0.74 dan 0.69 g/cm³, manakala kebolehlaluan pulpa terpukul dan tidak terpukul adalah masing-masing 250 dan 415 ml. Kertas menggunakan pulpa terpukul menunjukkan kelebihan yang signifikan bagi sifat-sifat mekanikal masing-masing bagi indeks tensil pada 79.57 Nm/g, indeks kepecahan pada 5.70 kPa.m², indeks koyakan pada 4.17 mNm²/g dan kelipatan pada 508 berbanding dengan kertas menggunakan pulpa tidak terpukul pada 67.28 Nm/g, 4.98 kPa.m², 3.28 mNm²/g dan 195. Sementara itu, sifat-sifat optikal bagi kedua-dua kertas yang menggunakan pulpa terpukul dan tidak terpukul memperlihatkan nilai yang hampir sama. Nilai opasiti dan kecerahan bagi kertas menggunakan pulpa terpukul masing-masing adalah 99.81 dan 32.44%, manakala kertas menggunakan pulpa tidak terpukul menghasilkan nilai opasiti pada 99.88% dan kecerahan pada 33.58%.