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ORIGINAL ARTICLE

MEA-PULPING OF SUGARCANE BAGASSE: EFFECT OF FIBER MORPHOLOGY AND BEATING TREATMENT ON PROPERTIES OF FURNISHED PAPER

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ABSTRACT

This paper presents the results of investigations on the suitability of MEA pulping of Sugarcane Bagasse (agro-biomass) for pulp and paper production. **Objectives**: To develop an Environmental Friendly Process Technology for converting Sugarcane Bagasse (Agro-wastes viewed as alternative raw material to wood) to pulp and paper. **Method**: Sugarcane Bagasse was characterized and properties like pulp yield, holocellulose content, lignin content, kappa number, viscosity, and brightness of the resulting pulp amongst others were determined. Excel 2016 was used to analyze the effect of operational variables otherwise known as the independent variables (i.e. temperature, cooking time, MEA concentration and liquid/solid ratio) and properties of bio-based material on pulp screened yield and strength properties of furnished paper (i.e. dependent variables) which include tear index, tensile index, burst index and folding endurance with errors less than 15% in all cases were determined. Influence of the independent variables in the pulping of Sugarcane Bagasse [viz. the effects that the MEA concentration (75%), temperature (150oC), time (90min.) on the yield and strength properties of furnished paper was investigated. Paper samples produced were tested for various strength properties. **Results**: The holocellulose (58.7%), α-cellulose (37.0%), and lignin (19.5%) contents are similar to wood materials, and various non-wood materials, but the fiber length is longer (1.7 mm). The MEA-cooking operation produced a pulp yield of 52.23% and a reject of 2.34% furnishing a pulp screened yield of 49.89%. The resultant pulp was subsequently bleached to a kappa number of 19.2 furnishing brightness level in the range of 90-94%. **Conclusion and Recommendation**: The physical properties, tear index (18 mN.m2/g), tensile index (86Nm/g), Burst index (5.9 kPa.m2/g) and folding endurance (97) recommend the cellulosic pulp from Sugarcane Bagasse obtained from the MEA process for strengthening the virgin fiber in recycled papers and also for developing certain types of printing and packaging papers. Kraft, soda and soda-AQ processes have been the most frequently used for softwood but in comparison to MEA-pulping process, higher yield at the same kappa number and better delignification without environmental damage due to lack of sulphur emissions was achieved. The Kappa number range (10.8-19.8), viscosity (290-820 ml/g) and brightness (81.5-93.2%) of these cellulosic pulp materials are appropriate for high-brightness printing papers.
Keywords: *Sugarcane Bagasse, MEA-pulping; kappa number; Lignin; Kraft pulping, tensile index, Burst index.*

1. INTRODUCTION

The pulp and paper industry is one of the largest sectors in the world of industrial production and remains a growth industry globally constituting well over $200 billion with volumes forecast to rise up to 50% by 2035 (i.e., an additional 200 million tons) with most of the growth occurring in the packaging and tissue sectors which constitutes the entirety of the bagasse-based paper sector [1]. This growth will occur in emerging economies and as the growth is occurring other economies will have net negative growth of 33 million tons by 2035 amidst the rapid decline in newsprint consumption. Hence, it is reasonable to presume that bagasse will grow in importance as a paper feedstock. Estimates for the amount of bagasse used in the production of pulp and paper products vary but the general consensus is that it accounts for 2–5% of global production, making it one of the highest revenue earners for the global sugarcane industry [2].

Apart from the impracticality of using bagasse to meet demand for paper, initial attempts to use bagasse for paper manufacture were unsuccessful primarily because the presence of pith is extremely detrimental to the papermaking process [3, 4, 5]. In particular, bagasse pith severely reduces permeability and hence reduces paper productivity by around 30% when bagasse-based pulp is used instead of wood-based pulp [6, 7, 8, 9, 10, 11]. The short pith material blocks the holes in pores of the paper mat, preventing water from draining through it, reducing the production rate and various quality characteristics of the final paper product. Initial problems with overcooking and supply-side issues were secondary factors, which also prevented the development of bagasse as a papermaking feedstock. For these reasons, interest in the suitability of bagasse for making paper stopped for more than 100 years. Using wood for papermaking was appropriate in tropical regions of the world which had abundant forest resources, however, many emerging countries that did not have abundant forests became dependent on imports of paper from developed countries. Many of these countries recognized the need for local paper production in the first half of the 20th century and the use of bagasse for paper production was revisited. Some of the early developmental work was funded by the United Nations programs in the 1950s and 1960s [12, 13, 14].

Advances in pulp and paper technology offer potential opportunities for economic utilization of agro-industrial residues such as sugarcane bagasse. The impulse that triggered the study on sugarcane bagasse (agro-biomass) as an alternative to wood cellulose for pulp and paper production stem from its abundant availability as the major by-product of the sugar cane industry containing about 50% cellulose, 25% hemicellulose and 25% lignin and can serve as an ideal substrate for the production of paper pulp. Research investigation showed that sugarcane bagasse has lowest content of silica, 9.78% and highest content of carbon 90.22% compare to rice straw and rice husk [15]. Bagasse is used for each of the four main paper categories, namely packaging and boxes, printing, writing and photocopier paper, tissues, and newsprint. Numerous comprehensive texts have a more in-depth analysis of the science of pulp and paper manufacture [16, 17]. This paper investigates the suitability of MEA pulping of Sugarcane Bagasse (agro-biomass), viewed as alternative raw material for pulp and paper production.

2. MATERIALS AND METHODS

The Sugarcane bagasse used in this experimental work was obtained during post-harvest treatment in Minna, Niger State, Nigeria.

2.1 Raw material characterization

Prior to chemical characterization and pulping, the raw material was washed, cleaned, sorted to remove foreign matters and air-dried, then stored to less than 60% relative humidity and aerated from time to time, to avoid decay. Following drying at ambient temperature, the raw material was cold-ground in a Wiley mill, to avoid altering its composition, permeating 0.25mm and retained on a 0.40mm sieve to keep size fractions between 0.25 and 0.40 mm using No. 25 and 40 of the Tyler series in accordance with TAPPI Standard T12–oS–75. Particles larger than 0.40 mm are inefficiently attacked by the chemical reagents, whereas those below 0.25 mm can cause filtering problems. The sample was characterized by analyzing its content of moisture, hot water solubility, klason lignin, α-cellulose, 1% NaOH solubility, total extractives and ash. Standard procedures were used for the analyses of these parameters and these procedures are outlined in Table 1.

Table 1 : Standards used in the Chemical Characterization.

Agro-biomass	Standards	R
Sample preparation	TAPPI Standard Test Method T 257 om-02	[18]
Moisture	TAPPI Standard Test Method T 412 om-06	[19]
Hot water solubility	TAPPI Standard Test Method T 207 cm-99	[20]
Total Extractives	TAPPI Standard Test Method T 204 cm-97	[21]
Acid insoluble (klason) lignin	TAPPI Standard Test Method T 222 om-02	[22]
Alpha (α)-cellulose	TAPPI Standard Test Method T 203 os-74	[23]
1% NaOH solubility	TAPPI Standard Test Method T212 om-02	[24]
Ash	TAPPI Standard Test Method T211 om -02	[25]
Holocellulose	TAPPI standard Test method T9m-54	[26]
Kappa No.	TAPPI Standard Test Method T236 om-13	[27]
Viscosity	TAPPI Standard Test Method T230 om-08	[28]
Brightness	**TAPPI Standard Test Method T452 om-**	[29]

2.2 Determination of Fiber Morphology

Small slivers were obtained and macerated with 10 ml of 67% HNO_3 and boiled in a water bath ($100^o \pm 2^oC$) for 10 min [30]. The slivers were then washed, placed in small flasks with 50 ml distilled water and the fiber bundles were separated into individual fibers using a small mixer with a plastic end to avoid fiber breaking. The macerated fiber suspension was finally placed on a slide (standard, 7.5 cm × 2.5 cm) by means of a medicine dropper. For fiber diameter, lumen diameter and cell wall thickness determination, cross-sections were obtained from the same height/length as above and were stained with1:1 aniline sulfate–glycerin mixture to enhance cell-wall visibility (cell walls retain a characteristic yellowish color). All fiber samples were viewed under a calibrated microscope; a total of 25 randomly chosen fibers were measured. All samples were measured in a swollen condition.

2.3 Outline of the Production Process

Figure 1 illustrates the process of making paper from Empty Fruit Bunch (EFB) of Oil Palm. The sample was characterized chemically and morphologically and converted into brown pulp at a delignification degree of 18.2 kappa from MEA Process. The resulting pulps was fully bleached by the D1-Ep-D2 sequence and characterized for its beatability, drainability and physical-mechanical properties.

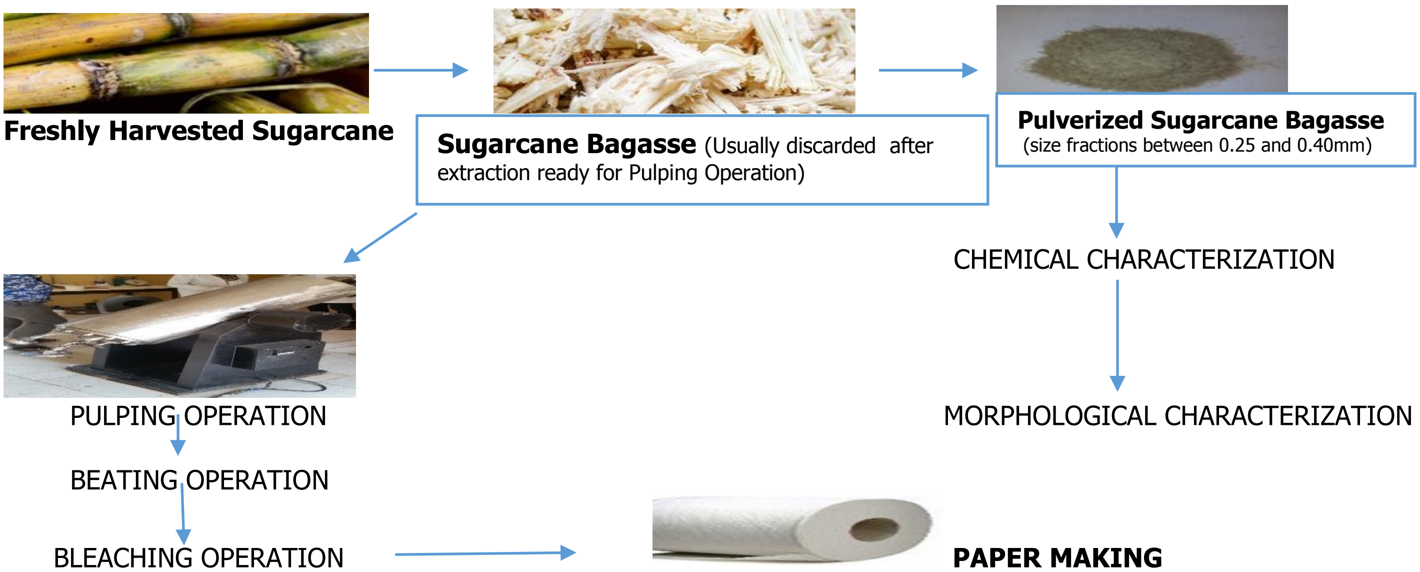


Figure 1: Steps in Sugarcane Bagasse (Agro-biomass) fractionation and conversion to paper

2.4 Description of the Pulp and Paper-making Process

After the post-harvest treatment, the sample was shredded and Prior to chemical characterization and pulping, a portion of the shredded sample was washed, cleaned, sorted to remove foreign matters and air-dried, then stored to less than 60% relative humidity and aerated from time to time, to avoid decay. Following drying at ambient temperature, the raw material was cold-ground in a Wiley mill, to avoid altering its composition, permeating 0.25mm (because samples below 0.25 mm can cause filtering problems) and retained on a 0.40mm sieve (because particles larger than 0.40 mm are inefficiently attacked by the chemical reagents) to keep size fractions between 0.25 and 0.40 mm using No. 25 and 40 of the Tyler series in accordance with TAPPI Standard T12 – oS – 75. This portion of the sample was characterized by analyzing its content of moisture, hot water solubility, klason lignin, α-cellulose, total extractives and ash. Standard procedures were used for the analyses of these parameters and these procedures are outlined in table 1. The second portion of the shredded sample was subjected to a thorough cleaning process, 2kg of air-dry sample was loaded into a 15 L capacity batch reactor (digester) with eight (8) liter cooking liquor at liquor-sample ratio of 4:1. The digester is furnished with an outer electrical heating jacket. The lid of the digester was firmly bolted to prevent leakage, the digester was switched on and the time of rise of temperature and pressure was noted at intervals of five (5) minutes. The content of the digester was stirred while in operation by rotating the vessel via a motor connected through a rotary axle to a control unit, including measurement and control instruments of pressure and temperature, to facilitate attainment of the working temperature (5ºC/min). The pulping temperatures gradually rose to the maximum cooking temperature of 150oC within a period of 61minutes and allowed to be steady at this temperature for minimum of 29minutes. The digester was switched off after maximum cooking period of 90 minutes from start of operation and allowed to cool below 60oC before the content were blown down. The digester's initial temperature, pressure and starting time were all noted, and the various changes in these parameters were also recorded. The resultant pulp was subjected to thorough washing with plenty of water. When it was observed that subsequent washing resulted in no further change in color, the pulp was transferred into the valley beater for processing into a more refined pulp before the bleaching operation.

Table 2: Pulping Conditions for the Sample (Sugarcane Bagasse) Investigated.

Conditions of Pulping Operation	Parameters
Air dry weight of Sugarcane Bagasse (kg) (A.D)	2
Liquor charge	75.0% MEA
Liquor/biomass ratio	4
Maximum cooking temperature (°C)	150
Time to reach maximum temperature (minutes)	61
Time at maximum temperature (minutes)	29
Over-all cooking time (minutes)	90
Blow-down temperature (^{o}C)	60

3. RESULTS AND DISCUSSION

Chemical analyses of sugarcane bagasse was conducted. Table 3 illustrates the results of the characteristics obtained

Table 3: Chemical Characterization of Sugarcane Bagasse.

Parameters	Sugarcane Bagasse (Agro-biomass)
Source of Sample	Minna-Northern Nigeria
Moisture content (%)	4.50
Hot Water Solubility (%) 80-95°C for 0.5hr	3.12
Extractives (%)	5.67
Ash (%)	6.80
Alpha-cellulose (%)	37.0
Lignin (%)	19.50
Holocellulose (%)	58.70

The moisture content and hot water solubility of sugarcane bagasse is quite low, while the extractive content is also low compared to other agricultural residues investigated in previous studies which means that sugarcane bagasse contained less substances like waxes, fats, resins, phytosterols, non-volatile hydrocarbons, low molecular weight carbohydrates, salts and other water-soluble substances. A higher content of extractives would be converted into pitch, which would adversely affect the runnability of process equipment and the quality of paper, because of shadow marking. Sugarcane bagasse has low content of extractives hence would require a moderately low dose of pulping liquor to neutralize acidic extractive, which would have little or no effect on the pulp yield and might create less digester corrosion caused by extractives. The higher the lignin content, the greater the stiffness of fibers. Lignin contents in sugarcane bagasse is slightly high and almost similar with that of the softwood. As observed in Table 3, Klason lignin contents in sugarcane bagasse is (19.50%). In practice, this means that these materials would need milder pulping conditions (lower temperatures and chemical charges) in order to reach a satisfactory kappa number and it would also undergo bleaching more easily and with the utilization of fewer chemicals. The average fiber dimensions of sugarcane bagasse investigated in this research study is shown in Tables 4. In producing paper, increasing the amount of cellulose and decreasing value of lignin, the extractive content, and ash caused increase of yield, decrease in chemical, material consumption, and cooking time. Papers made from this type of fibers might show reduced water absorbency.

Table 4: Morphological properties of Sugarcane Bagasse (Nigeria-cultivated Agro-based fiber).

Plant Materials	Fibre length, (L), (mm)	Fibre diameter, (D), (µm)	Fibre Lumen, (d), diameter (µm)	Fibre wall/Cell wall thickness, (w), (µm)
Sugar Cane Bagasse	1.70	21.0	11.9	6.2

Figure 2: Sugarcane Bagasse Fiber image on a projection microscope.

The morphological parameters of sugarcane bagasse investigated are presented in table 4. The Fiber length of sugarcane bagasse is 1.7, the Fiber diameter of sugarcane bagasse is 21.0µm, the fiber lumen width is 11.9µm while the Fiber cell wall thickness is 6.2µm. Softwood fiber is between 3-5 mm long and about 39 to 41 µm wide, meaning that sugarcane bagasse length and width are about 76.66% to 86.0% and 65.46% to 85.49% lower, respectively, than those of softwood.

Table 5: Biometry/Morphological Indices of Fiber Dimensions

Plant materials	Derived Values			
	Slenderness ratio, L/D	Flexibility coefficient, (d/D)×100	Runkel ratio, 2w/d	Rigidity Coefficient,2w/D
Sugar Cane Bagasse	80.95	56.67	1.04	0.59

Influence of morphological properties on Biometry (Slenderness, Flexibility, Runkel and Rigidity coefficient) of the sugarcane bagasse fiber investigated are shown in Tables 5. The Slenderness ratio of Sugarcane Bagasse is 80.95 while the Flexibility coefficient is 56.67. Generally, there are four different types of fibers which are classified under flexibility ratio [31]: (1) High elastic fibers having elasticity coefficient greater than 75. Elastic fibers having elasticity ratio between 50 to75. Rigid fibers having elasticity ratio between30 to 50. High rigid fibers having elasticity ratio less than 30. According to this classification, flexibility coefficient of sugarcane bagasse is in uniformity with hardwoods. When Runkel proportion is greater than 1, it indicates that a fiber has thick wall and cellulose obtained from this type of fiber is less suitable for paper production; when it is equal to 1, it specifies that a cell wall has medium thickness and cellulose obtained from this type of fiber is suitable for paper production. When the rate is less than 1, it points out that a cell wall is thin and cellulose obtained from this fiber is the most suitable for production of paper [32]. Runkel value of sugarcane bagasse is approximately equal to 1 and according to the Runkel classification, it specifies that the cell wall has medium thickness and cellulose obtained from this type of fiber is suitable for paper production. The high content of lignin in sugarcane bagasse (19.50%) made the fibers appear tougher and stiffer compared to other fibers like pineapple leaves, wheat straws, corn stalk/sheets, coconut fruit bunch, elephant and lemon grass and other fibrous agro-wastes furnishing rigidity coefficient of these bio-base materials following the order: (Highest) Bagasse (0.59)>Coconut (0.58)> EFB(0.57)> Pineapple leaves(0.56) > Corn(0.50)> Lemon grass (0.44)> kenaf(0.39) > Elephant grass (0.34)> Wheat (0.17) > Rice(0.06)> (lowest) 32. This is probably because lignin provides compressive strength to plant tissue and individual fibers and stiffens the cell walls, to protect carbohydrates from chemical and physical damages. Detailed research work on these agro-wastes is not included in this report.

Table 6: Levels of Different Parameters Investigated.

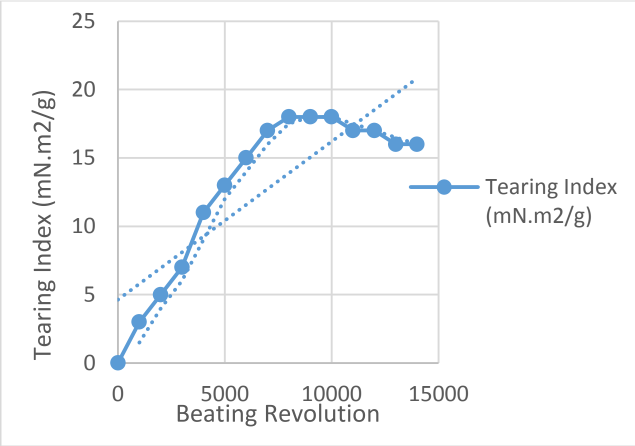
Pulp Properties	Parameters
Pulp yield (%)	52.23
Pulp Screened Yield (%)	49.89
Reject (%)	2.34
Viscosity (ml/g)	470
Kappa number	19.2
Brightness (%)	92

The MEA-cooking operation produced a pulp yield of 52.23% and a reject of 2.34% furnishing a pulp screened yield of 49.89%. The resultant pulp was subsequently bleached to a kappa number of 19.2 furnishing brightness level in the range of 90-94%. Paper samples produced were tested for various strength properties.

Table 7: Effect of beating revolution on Pulp Freeness and Tearing index of furnished Paper

Beating (revolution)	Freeness (ml/s)	Tearing Index ($mN.m^2/g$)
0	820	0
1000	690	3
2000	650	5
3000	530	7
4000	480	11
5000	430	13
6000	400	15
7000	360	17
8000	340	18
9000	330	18
10000	320	18
11000	310	17
12000	300	17
13000	290	16
14000	290	16

The tear index values of sugarcane bagasse pulp sheets after beating to different beating levels indicate non-linear relationship between tear index and morphological characteristics. It increased from 3.0 to 18 mNm2 /g on beating from 690 to 340 CSF (ml) and on further beating from 340 ml CSF to 290 ml CSF, it drops from 18 to 16 mNm2 /g. Relationship between double fold and morphological characteristics of pulp fibers after beating of pulp up to different levels revealed that CSF, curl, broken ends and fine elements (% in area) significantly affect the double fold number of sugarcane bagasse pulp hand-sheets. Broken ends account for 54.7 % variation. The other factors affecting double fold are CSF, Curl and Fines elements (% in area). The multiple regression analysis involving combined effect of these variables was found to account for 96.5 % of the total variation. The regression models of relationship between tensile index, burst index & double fold (dependent variables) and various morphological characteristics (independent variables) were validated using experimental data limits. The percent deviation between experimental and the calculated values of tensile index were found to be within the acceptable limits. However in case of burst index and double fold the percent deviation between experimental and the calculated values were observed to be on higher side (Table 9 and 10). This is due to non-linear relationship between CSF values and the double fold values in the higher beating levels.



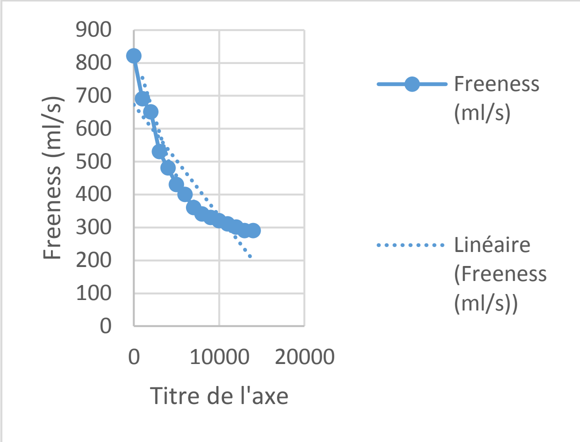
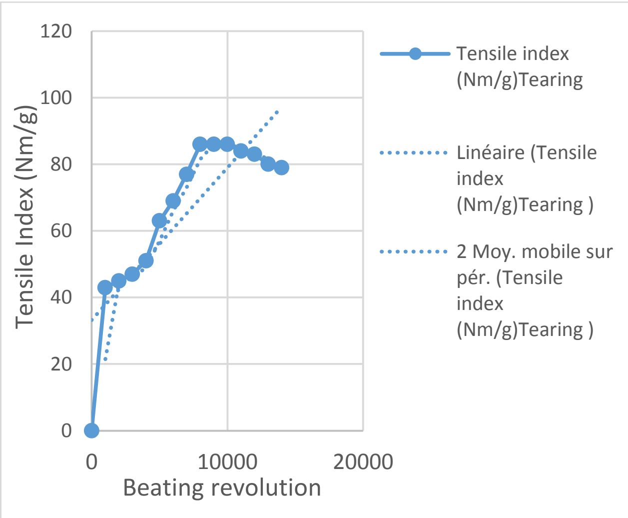


Figure 3: Effect of Beating Treatment on Tearing Index. **Figure 4**: Effect of Beating Treatment on Tearing Freeness.

Table 8: Effect of Pulp Beating Treatment on Tensile index at various beating revolutions.

Beating (revolution)	Freeness (ml/s)	Tensile index (Nm/g)Tearing
0	820	0
1000	690	43
2000	650	45
3000	530	47
4000	480	51
5000	430	63
6000	400	69
7000	360	77
8000	340	86
9000	330	86
10000	320	86
11000	310	84
12000	300	83
13000	290	80
14000	290	79



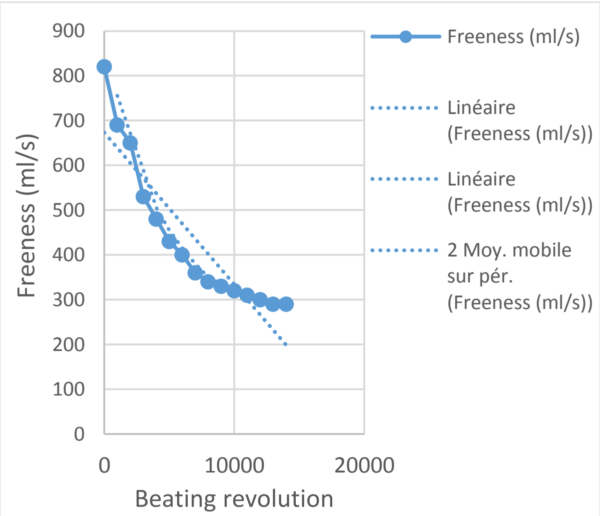
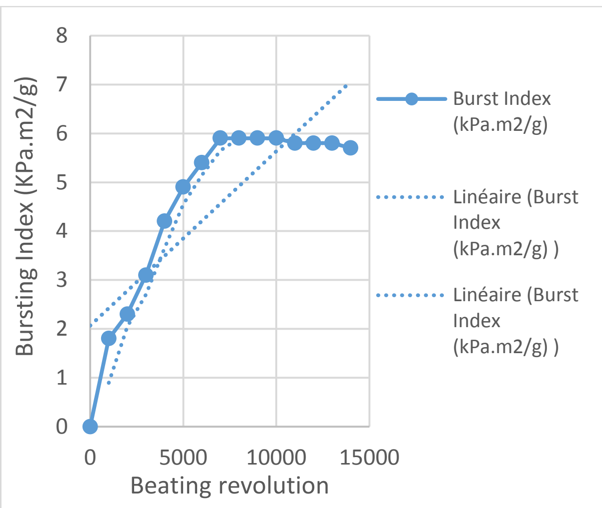


Figure 5: Effect of Beating Treatment on Tensile Index **Figure 6**: Effect of Beating Treatment on Freeness

Table 9: Effect of Pulp Beating Treatment on Burst index at various beating revolutions.

Beating (revolution)	Freeness (ml/s)	Burst Index (kPa.m^2/g)
0	820	0
1000	690	1.8
2000	650	2.3
3000	530	3.1
4000	480	4.2
5000	430	4.9
6000	400	5.4
7000	360	5.9
8000	340	5.9
9000	330	5.9
10000	320	5.9
11000	310	5.8
12000	300	5.8
13000	290	5.8
14000	290	5.7

Analysis carried out on morphological characteristics of pulp fibers obtained from sugarcane bagasse revealed that fiber length and fiber coarseness significantly affect the burst index of furnished hand-sheet. Coarseness being most dominating individual variable and account for 83.0%, while fiber length accounts for 96.6% towards burst index variation. The multiple regression analysis involving combined effect of these variables accounted for 99.0% of the total variation.



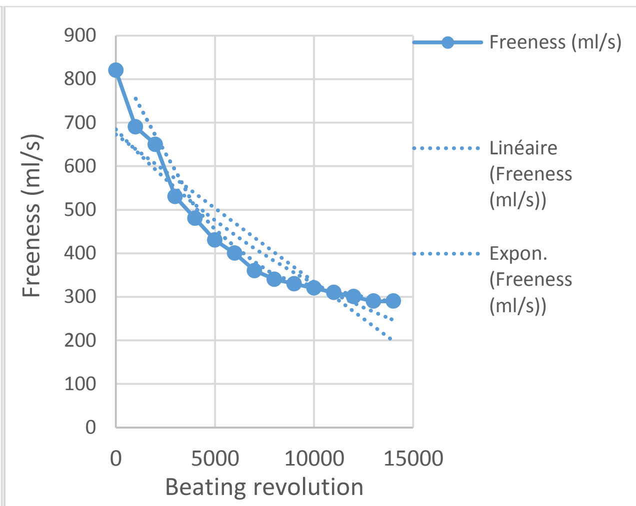


Figure 7: Effect of Beating Treatment on Bursting Index **Figure 8**: Effect of Beating Treatment on Freeness

Table 10: Effect of Pulp Beating Treatment on Folding Endurance at various beating revolutions.

Beating (revolution)	Freeness (ml/s)	Folding Endurance, no
0	820	0
1000	690	27
2000	650	40
3000	530	54
4000	480	73
5000	430	80
6000	400	85
7000	360	92
8000	340	97
9000	330	97
10000	320	95
11000	310	95
12000	300	94
13000	290	94
14000	290	93

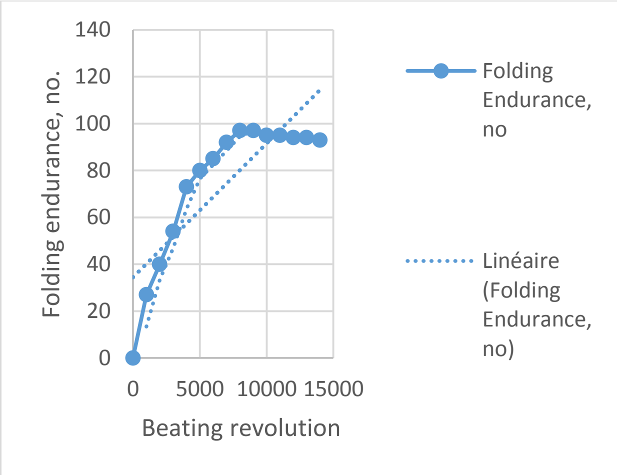


Figure 9: Effect of Beating Treatment on Folding Endurance.

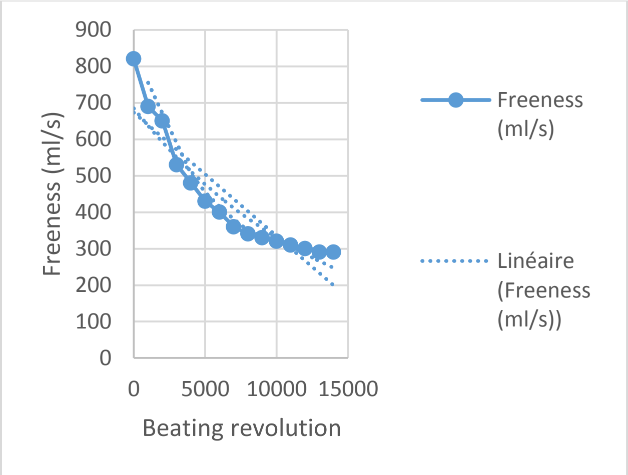


Figure 10: Effect of Beating Treatment on Freeness.

4. CONCLUSION AND RECOMMENDATION

Pulping is a chemical-technological process for the production of cellulose fibers for paper-making from woods and other plant materials. Paper strength depends on the cellulose content of a raw plant material. Cellulose content was at a satisfactory level (above 40%) for the fiber utilized in the present study. Overall, bagasse fibers appear to be suitable for producing paper products due to lower lignin and extractive components as well as higher in cellulose content. Literature studies about softwoods revealed that elasticity coefficient was found within the range 50-70. Examining this information given, and comparing it with data generated in this research study, it seems sugarcane bagasse is similar to other softwood fibers. The Kappa number range (10.8-19.8), viscosity (290-820 ml/g) and brightness (81.5-93.2%) of these cellulosic pulp materials are appropriate for high-brightness printing papers. The physical properties tear index (18 mN.m2/g), tensile index (86Nm/g), Burst index (5.9 kPa.m2/g) and folding endurance (97) recommend the cellulosic pulp from Sugarcane Bagasse obtained from the MEA process for strengthening the virgin fiber in recycled papers and also for developing certain types of printing and packaging papers. Kraft, soda and soda-AQ processes have been the most frequently used for softwood but in comparison to MEA-pulping process, higher yield at the same kappa number and better delignification without environmental damage due to lack of sulphur emissions was achieved. Depending on all the investigation carried out, it is possible to conclude that sugarcane bagasse is suitable for high brightness paper production. Summary of analyses of data generated in this research work in comparison with literature and previous studies on wheat, corn and rice fiber residues, sugarcane bagasse fall within the range of elastic fiber which means that it is sufficiently elastic; hence it is suitable to be used for the production of fiber plate, rigid cardboard, cardboard and certain types of high brightness printing paper. Bagasse is also well suited for tissue, corrugating medium and writing paper when used in blend with other types of fiber (i.e. kenaf fiber).

Agricultural wastes, annual plants and non-wood materials have attained such importance in the world cellulose economy, that to ignore their relevance in the pulp and paper industry would result in a complete lack of balance. In a world where virgin pulp sources are scarce, and environmental concerns require reduction in cutting down green forest, agricultural residues could become a good source of fiber in the tropical regions of the world where they are grown. The search for local long fiber pulp material which can be easily propagated remains one of the most important key desirderatum for the eventual resuscitation of the present mom bund paper industries of Nigeria. One important way of stemming the tide of imports is to find a good substitute to fine pulp for the use of the Nigeria paper companies when they eventually start producing. Besides being an innovation and new entry into the pulp map, sugarcane bagasse can become the best gift of FIIRO into the future pulp market of the tropical world.

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