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Performance of bagasse as fiber resource in tissue paper manufacture

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Abstract: This study investigates the quality and suitability of bagasse as raw material for tissue paper production in Egypt. Bagasse pulp (BP) was mixed with Softwood (SW) and Hardwood (HW) pulps with various compositions. The best blending ratio was studied. Various hand sheets properties were measured as dry tensile and wet tensile index, zeta potential, brightness, roughness, absorbency. chemical analysis and the effect of refining were also investigated. SEM was used to investigate the morphology of the prepared samples. The results showed that the improvement of tensile index of dry strength reached to 15.18% using bagasse in hand sheet by the sample (20 % SW + 20 % HW + 60 % BP), and the improvement in wet strength reached to 16.53 % at the sample (20% SW+ 80% BP). Bagasse pulp gave better result when refined at 250 rpm rather than hardwood which refined at 2500 rpm. The negative value of zeta potential of the mixed furnish was increased as the bagasse pulp percentage was increased, addition of additives decrease of the negative value of zeta potential. Paper roughness was decreased, the best improvement was appeared by the sample (20 % SW+60 % HW+ 20 % BP) it reached to 11.6 %. SEM analysis showed that the addition of bagasse kept the homogeneity of the sheet.

keywords: Bagasse, Hard wood and soft wood, tensile index, Zeta potential, roughness, Brightness

1.Introduction

The Requirements of paper and paperboard are growing day by day and the resources are not enough for the global demands (1) (2). Traditionally, papermaking industry is largely dependent on softwood & hardwood resources. Egypt faces a substantial shortage of fibrous raw materials for the production of pulp and paper from wood material. On the other hand, the demand for paper and tissue products is increasing. Although, the increasing demand for fiber and the limited availability of additional forest resources made the industry explore different fiber options for raw material which include agricultural residues such as wheat, rice straws, or sugarcane bagasse or bamboo (3)(4). There is a scarcity of wood resources despite the fact that the world has enough forest soil to provide wood for the earth's peoples and that with good forest management and consumption enough wood could be produced to supply all existing needs. This shortage is all the more serious because of rising demands for wood fibers for pulp and a growing wood chemical industry. So, virgin wood are very important to meet the demands of the forest products industry. The use of non-wood plant fibers for pulp and papermaking in these regions is not a problem of choice but a matter of requirement (5).

Sugarcane production is one of the oldest industries in Egypt; cane planting is specifically concentrated in the area of Upper Egypt. The sugarcane cropping pattern, cultivated areas, its uses are showing the total amount of cane cultivated in Upper Egypt is about 16 million tons per year (6). Bagasse is the fibrous residue that remains after sugar cane crashes to extract its juice and is widely used as a renewable resource in the manufacture of pulp and paper products and in construction materials. Using agricultural yield rather than wood has the added advantages of reducing deforestation. Bagasse fibres are approximately 1.7 mm (7) and are well suited for tissue, corrugating material, newsprint, and paper writing. Bagasse contains 65-68% fiber, 25-30% pith, 2% sugar and 1-2% minerals. Bagasse fibre dimensions are fairly similar to those of hardwood fibers such as eucalyptus (8). However, some features of bagasse such as high contents of pith and silica require that its pulping process be different than that for eucalyptus chips. In the sugar factories, sucrose is extracted from the parenchyma cells mainly located in the pith. Some of the processing difficulties associated with bagasse pulps are attributed to these short pith materials (length < 0.3 mm) which can block the holes in the paper mat, thus decreasing drainage, production rate, and paper quality (9). These materials could be removed from the crushed cane by a pretreatment that could be beneficial to the subsequent pulping and bleaching processes (10).

In hygienic tissue paper manufacture, some additives are added for two functions; the first one is to improve the paper properties such as dry strength, wets strength, absorbency and smoothness and the second one is to improve the machine runnability and performance. The addition of the chemicals depends on the paper grade, machine speed, properties of different fibers and market demands (11).

This work aimed to use agricultural waste as bagasse rather than wood in tissue paper to reduce the importing of Hardwood from outside and using local pulp. Bagasse pulp was mixed with Softwood (SW) and Hardwood (HW) pulps with various compositions. The best blending ratio of wood pulps and bagasse pulp to enhance tissue properties studied. Besides the effect of some additives as dry strength, wet strength agent and softener also investigated.

I. Experimental

II.1 Materials

Two types of wood fibres were used: Softwood pulp (SW) named Botina KMI supplied by Metsa-Fibre (Finland), and hardwood pulp (HW) named Suzano supplied by Suzano Papel Celulose (Brazil). The Nonwood pulp was bagasse (BP) produced in Egypt. Wet Strength Agent (Kymene 970 EU), Softener Agent (Prosoft TQ218) & Dry strength additive (Hercobond 8922,) were supplied by Solenis company.

Procedureandsamplecharacterization

Extractive material

A 10 ± 1 g of cellulose sample was weighed in a dried conical flask (initial weight W_i) and cut into small pieces. The sample was placed in a Soxhlet extraction tube then 250 ml pure acetone was added, and the sample was heated to 200 - 250°C. The acetone was circulated for 5 hours then it was left to be evaporated. After that, the conical flask was heated in drying oven at 105°C for 3 hours, and the weight was recorded (final weight W_f). The following formula was used to calculate the extractive materials. The test was determined according to ISO 14453

Extractive materials % = (W_F – Wi) (g.)/ Weight of cellulose sample (10 ± 1g.)

Ash content

was estimated by igniting an exactly weighed sample in a muffle furnace, Oven and Furnace M01003~1 was used to measure the ash and consistency, for 30 minutes at 400ºC, then for 45 minutes at 850º C before being gravimetrically estimated (Tappi standard 211-om 85). The percentage of ash was calculated from the equation:

$Ash\ Content\ \% = (Weigt\ of\ ash\ /Weigt\ of\ dry\ material) \times 100.$

Chemical analysis

is done according to TAPPI standard, α-cellulose content was measured according to TAPPI T 203 cm-99, Hemicellulose content was measured according to T 223 cm-01 and lignin content was measured according to T 222 om-02.

Pulping Beating process

Disintegrator with acrylic pot X.10.401.111 from Noviprofibre company was used for the pulping beating process. The moisture content of the pulp was calculated. Then 30 g of the dry pulp sample (± 0.5 g) was added to water, the total volume was completed to 2000 ml (± 25 ml). The sample was added on the disintegrator at 30,000 Rotary, after completing the mixing, the sample was filtered through a Büchner Funnel and it was weighed. Water was added to bring its weight to 300 g. (±0.5 g.). The sample was transferred to the housing's wall of PFI – Mill at 2500 rpm for SW and HW according to

ISO-5264-2. For bagasse, various revolutions were applied between 250 and 2500 rpm. The extent of refining of the different pulp samples was monitored by determination of Schopper_ Riegler drainability (SR) on the pulp suspensions after refining using Schopper 10.403.x00 according to ISO 5267-1.

Then the pulp sample was transferred from the housing to a beaker and water was added to bring its volume to 2000 ml (± 25 ml), the sample was added again on the disintegrator at 10,000 rotaries, then the furnish pulp was mixed and the change in the percentage of SW to HW with bagasse can be made according to table 1.

Table 1 composition of samples

Furnish	**Softwood %**	**Hardwood %**	**Bagasse %**
1(control)	20	80	0
2	20	60	20
3	20	40	40
4	20	30	50
5	20	20	60
6	20	0	80

Dry strength agent (Hercobond 8922), wet strength agent (kymene 970 EU) softener (Prosoft TQ218) were separately added after mixing the pulps as shown in Table 1. All additives were added for measuring Brightness, Zeta Potential, Roughness and Absorbency for final quality.

Zeta potential

was determined by measuring the electrophoretic mobility of pulp suspensions by using Zetasizer 2000 (Malvern). Pulp suspensions were prepared in deionized water at 2% consistency. The suspensions were stirred for 2 hours and then filtered by using 70 µm Nylon fabrics. The filtrate was then injected in the capillary of the apparatus. Three measurements were performed, and the results were averaged.

Sheet preparation

The Rapid Kothen paper Forming Machine with 1 Dryer-1 KWT X.10.405.310 was used Sheet preparation. The consistency was reduced, and the sheet was formed with drying according to ISO 5269-2

Paper sheets characterization

Cobb 30 test according to ISO 535 was carried out; it determines the water absorbency of the paper sheet. Roughness was defined as the measurement of the extent to which the surface of the paper deviates from plane; the higher reading means more roughness. It was measured in ml/min by roughness tester (Bendtsen; model K531, Messmer Buchel) according to ISO 8791-2 standard. Horizontal 030121 was used to measure the tensile index and the wet tensile index of paper sheets according to ISO 5270-1. Brightness, Yellowing & opacity were measured by Spectrophotometer cm3630-N5900 according to ISO 2470. The surface of hand sheets has been observed using scanning electron microscopy (a Zeiss ULTRA55 Scanning Electron Microscope (SEM) with an acceleration voltage of 15 kV).

II. Results and discussion

Chemical composition of SW, HW and BP

Wood is essentially composed of cellulose, hemicelluloses, lignin, and extractives. Cellulose, the major chemical component of fiber wall and contributing 40-45% of the wood’s dry weight, it is composed of linear chains of D-glucose linked by ß-1,4-glycosidic bonds with the degree of polymerization from 10,000. Hemicellulose have lower polymerization (about 100-200). The side chains of hemicellulose polymers are monosaccharides. Lignin is a class of complex organic polymers that form key structural materials in the support tissues of vascular plants and some algae (12). The Chemical composition and fiber length of SW, HW and Bagasse pulp is shown in Table 2.

Table 2 the Chemical composition and fiber length of SW, HW and BP

Prosperities	**Bagasse**	**SW**	**HW**
Fiber Length (mm)	1.7(13)	min 1.8 company specs	0.77 company specs
α-Cellulose (%)	74.5	77.0	76
Hemi cellulose %	21.2	21.0	22.0
Klason lignin (%)	0.87	0.75	0.85
Extractives %	0.02	0.02	0.02
Ash Content %	1	0.7	0.6

III.2 Schopper Riegler (°SR)

In paper production the drainage resistance of pulp, which depends on the fibrillation grade, is one of the most important parameters in paper sheet formation and influences the runnability of the paper machine.

The most common method used for the determination of pulp's dewatering properties is the Schopper-Riegler degree (°SR), which enables us to control the refining process. The main purpose of refining is to increase the internal fibrillation and consequently fiber swelling and flexibility by cell wall degradation, and external fibrillation which results in increased outer surface area of fibers(14) .

In the production of tissue paper, the fibre suspension is to a large extent dewatered by removing water in the vacuum suction boxes, and it is important to maximize the amount of water removed by this technology in order to reduce the cost of the final dewatering and the energy consumption in the final drying of the sheet. Light refining is recommended (Schopper Riegler degrees between 22 and 35) for production of high-quality tissue paper and good machine runnability (11).

Figure 1 shows the °**SR** of the main pulp furnish. The Schopper decreased in the order BP (2500 rpm) > HW > BP (250 rpm) > SW. Refining the bagasse at 250 rpm achieved the target SR value around the ones of softwood and hardwood. Consequently 250 rpm was selected for its convenience for operation and the great reduction in energy consumption (15).

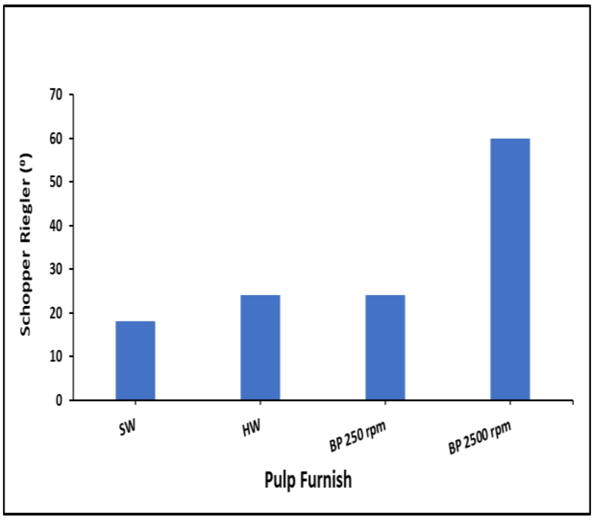

Fig 1. the shopper regular of the main furnish pulp

III.3 Tensile Strength

Figure 2 shows the breaking length of softwood (SW), hardwood (HW) and bagasse (BP) paper handsheets. The breaking length decreased in the order SW pulp > BP (refined at 2500 rpm) > BP (refined at 250 rpm) > HW. Although bagasse pulp was refined at low rpm (250), it shows strength value around the hardwood pulp which was beaten at 2500 rpm. This may be attributed to the longer fibre length of bagasse pulp. Length is one of the most important fibre properties. A long fibre can have more fibre joints and therefore create a stronger network compared to a shorter fibre.

Bagasse has fiber length around 1.7 mm (13) which is higher than the HW (0.77 mm) and approximately near the length of the SW fibers (1.8 mm). When it was beaten at 2500 rpm, the breaking length increased and showed a higher value than the hardwood pulp (15).

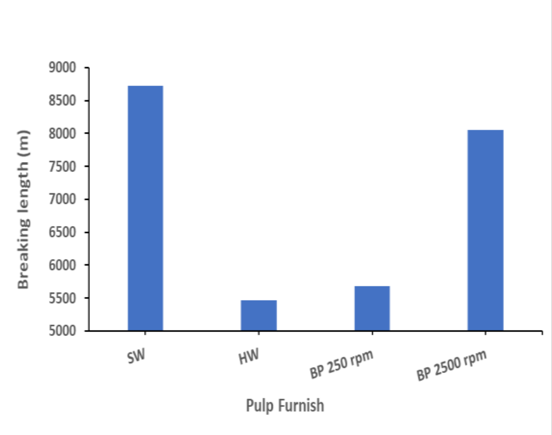

Fig 2. Breaking length of Softwood, Hardwood (refined at 2500rpm) and Bagasse pulp (refined at 2500 & 250 rpm)

Figure 3 shows the effect of increasing the addition level of bagasse pulp in the prepared handsheet furnish without and with using dry strength additive. The breaking length increased with increasing the addition of bagasse in pulp mixture. It reached to maximum value 6456 m at (20% SW+ 60% HW+20% BP) without addition of dry strength additive(the percent change was 10.15%), and it reached to 7034 m. after adding dry strength additive at the sample (20% SW+ 20% HW+60% BP). The improvement reached to 15.18%.

Dry strength is an inherent structural property of a paper sheet which is due primarily to the development of fibre to fibre bonds during consolidation and drying of the fibre network. The fibre-fibre held together by intermolecular forces (van der Waals; hydrogen bonding). Paper strength is dependent on the strength of individual fibres, the strength of interfibre bonds, the number of bonds (bonded area) and the distribution of fibres and bonds (formation). Paper strength additives may bring about improvement in one or more of the above factors, although it may be assumed that they are unlikely to affect the strength of single fibres. In tissue paper as an absorbent paper, the amount of fluid that can be held in the product during its use should be maximized via maintaining large air-filled spaced among the fibres in the structure. At the same time, the paper needs to be strong enough to run efficiency through various manufacturing and converting processes. Dry strength agents can be used to meet the strength requirements of the products.

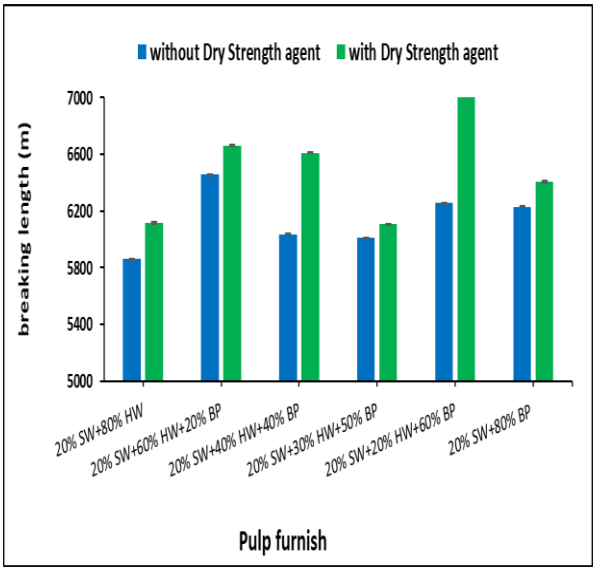

Fig 3. Breaking length of paper samples after mixing different types of pulp without and with adding Enzyme The dry strength additive used in this study was enzyme type (cellulase enzymes), which is related to the cellulose and hemicellulose family. The cellulases break down the fibrous cellulose (16). It causes the cell walls to be delaminated and break, and starts fibrillation. It is, of course, exactly what the mechanical refines do. The enzymes may however provide a more gentle targeted refining. Mills can reduce their energy requirement for pulp refining through the application of enzymes prior to refining. Those benefits can also be incorporated from the same facility into expanded production capacity. Enzymes are supposed to offer more benefits to those mills that don't have captive power generation and are constrained by capacity refining. Fiber changing enzymes may be used to achieve sheet quality that a mechanical refiner in a mill can't be able to achieve. The enzyme can also be used to allow less expensive pulps to be used to reduce production costs (16).

III. 4 Wet Strength

The fibre-fibre contacts in paper network structure are very sensitive to water, the extent of bonding decreasing steadily as the water content of the paper increases. As a result the efficiency of paper machines is significantly reduced by sheet breaks at the machine wet end. In addition, absorbency is an important property for towelling and other tissue products with the purpose of wiping liquids. Absorbent tissue product should be capable of readily absorbing water and retaining a high level of absorptivity until the end of the task without damage or breaking apart. To improve this low strength a number of wet strength additives have been applied (11).

In this study the wet breaking length of the mixed pulp significantly increased after addition wet strength additives as shown in Figure 4. The highest wet strength was obtained for samples (20%SW + 80% BP) and (20% SW +20% HW + 60% BP) the increase reached to16.53 %, and 13.39 %., respectively.

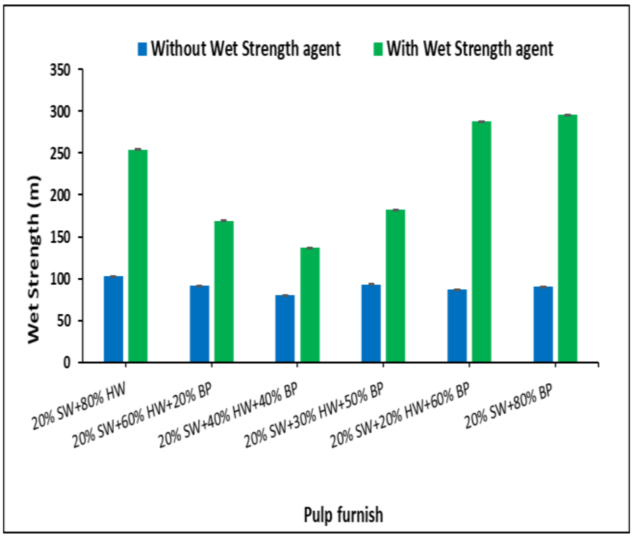

Fig 4. The wet tensile index of paper samples after mixing different types of pulp without and

with adding wet strength agent (Kymene 970 EU).

III.5 Zeta Potential

The cellulosic fibers usually carry a negative charge when suspended in water because of the presence of ionisable acidic groups. The charge of fibers may be a complex function of the chemical composition, state of ionization of the acid groups, and therefore the nature and amount of additional substances adsorbed on the fiber surface. The ionizable population depends on the sources of the fibers and the chemical treatments such as pulping and bleaching. The characteristics of any particular fiber surface also depend greatly on the degree of mechanical treatment. The zeta potential is a very important factor in the manufacture of paper. The optimum papermaking can be achieved when the particles have a zeta potential close to zero (18).

Table 3 represents the zeta potential measurements of pure pulp SW, HW and BP and mixed pulps before and after addition of additives.

BP has higher negative charge than the SW and HW. As shown in Table 3 for mixing furnish without adding additives, increasing the bagasse pulp percentage led to increase the negative value of the zeta potential, it means more chemicals can be added, like wet strength and softener agent. The zeta potential of the sample (20% SW+80% HW) changed from -2.4 to -3.07 by increasing BP percentage. It was changed to -0.57 by adding additives at the same sample, while it was increased by increasing BP percentage, but by less values than the cases of samples without additives (19).

Table 3 The zeta potential of the mixed Pulps before and after adding the additives

	Pulp Furnish	Zeta Potential (mv)	St. dev.
Pure pulps	SW	-2.83	0.028
	HW	-2.63	0.025
	BP 250 rpm	-4.3	0.038
without additives	20% SW+80% HW	-2.4	0.042
	20% SW+60% HW+20% BP	-2.41	0.038
	20% SW+40% HW+40% BP	-2.43	0.051
	20% SW+30% HW+50% BP	-2.86	0.039
	20% SW+20% HW+60% BP	-3.07	0.038
	20% SW+80% BP%	-3.05	0.03
with additives	20 SW%+80 HW%	-0.57	0.008
	20 SW%+60 HW%+20 BP%	-0.64	0.007
	20 SW%+40 HW%+40 BP%	-0.94	0.005
	20 SW%+30 HW%+50 BP%	-0.62	0.005
	20 SW%+20 HW%+60 BP%	-2.32	0.024
	20 SW%+80 BP%	-1.22	0.01

III.6 Brightness

Figure 5 reveals the handsheet brightness of the mixed pulps with and without additive addition. Increasing the percentages of bagasse pulp in paper furnish showed a slight increase in brightness, it reached to 84.08 % for the sample (20% SW +60% HW + 20 %BP). Addition of additives led to decreasing the paper brightness for all paper samples. The loss in brightness after addition of additives is occurred due to reducing the possible number of fiber-air interfaces. The reduction of fiber-air interfaces will result in reduced light scattering, which in turn results in lower brightness (20). The results show that the max decrease was obtained at the sample (20% SW +60% HW + 20 %BP), it reached to 2.6 % and the minimum decrease is 0.69% at the sample (20 %SW +20% HW + 60% BP).

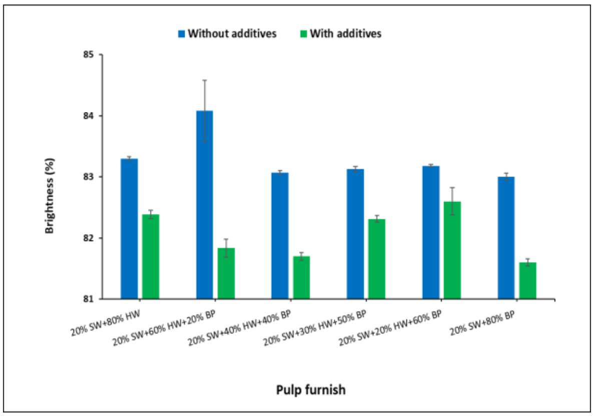

Fig 5. the brightness of pulp furnish before and after addition of additives.

III.7 Roughness

Figure 6 shows the roughness of mixed pulp before and after adding the softener agent (Prosoft TQ218). The highest value means more roughness. The roughness increased with increasing the percentage of bagasse pulp, while it was decreased by adding softener (21, 22). Addition of softener enhanced surface smoothness. Each sample is compared by itself before and after adding prosoft TQ218. The best improvement showed by the sample (20 % SW +80% HW), it was reached to 13.8 %. The improvement appeared by the sample (20 % SW+60 % HW+ 20 % BP) reached to 11.6 %. While that of the sample (20% SW + 30% HW + 50 % BP) reached to 8.5%.

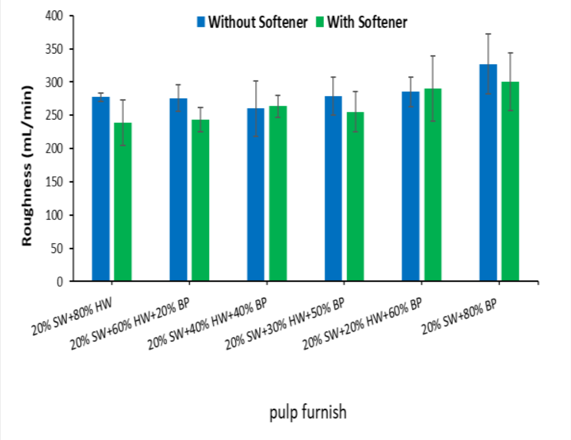

Fig 6. Roughness of paper sample before and after addition of softener.

III.8 Absorbency

When Paper products is touched with water, the first phenomena is surface wetting then the penetration of water inside the paper structure take place. The penetration process happens by swelling of the fiber as water is absorbed into the fiber cell wall, it causes change in volume and pore structure of paper (23)(24).

Wet strength additive has negative effect on absorbency. It can be explained by the preservation mechanism of the wet strength agent. This mechanism suggests that the resin crosslinks with itself surrounding the fiber-fiber contact area (volume), impeding fiber swelling and excluding water molecules so that a significant portion of hydrogen bond can be preserved (25). Figure 7 shows the effect of replacement of HW with Bagasse on Absorbency of tissue paper. It is observed that absorbency reached to 118.594 g/m^2 at the control sample (20 % SW+ 80 % HW) and it reached to maximum value 124.858 g/m^2 at the sample (20% SW+ 80% BP) without additives the improvement is 5.2 %. It is observed that absorbency reached to 112.728 g/ m^2 with additives in the control sample and it reached to 120.058 g/ m^2 at the sample (20% SW+ 60 % HW + 20 %BP) with additives, the improvement is 6.5 %.

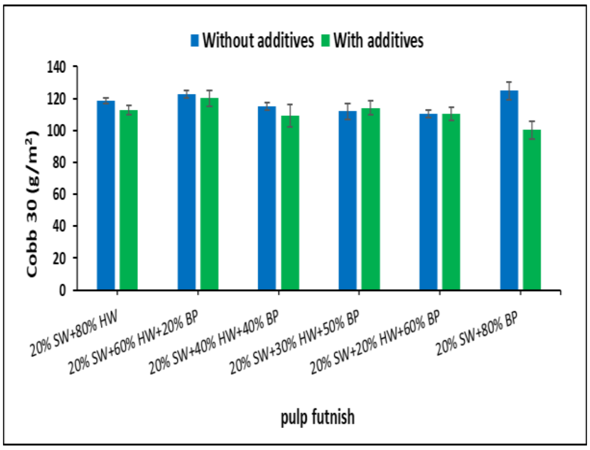

Fig 7. The absorbency of paper samples after mixing different types of pulp without *and with additives*

SEM results

Figure 8 shows scanning electron micrograph (SEM) of (a) Hardwood, (b) Softwood and (c) Bagasse hand sheets, at magnification 50µm. it is clear the difference between their fibre sizes.

Figure 9 shows scanning electron micrograph (SEM) of (a) sample (20% SW+20 %HW+60% BP) and (b) sample (20% SW+80% HW) hand sheets, at magnification 500µm.

By making a comparison between Figure 9 a and b, it was found that both samples have good homogenous formation with uniform chemical distribution. This result indicates that bagasse pulp can replace hard wood pulp in tissue paper with good effect on paper formation

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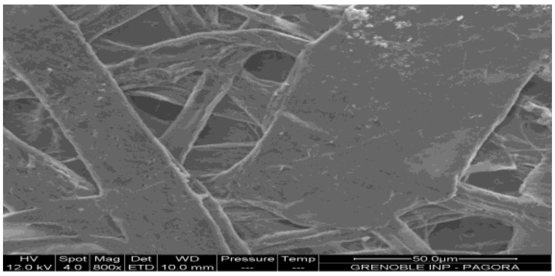
(a) Hardwood

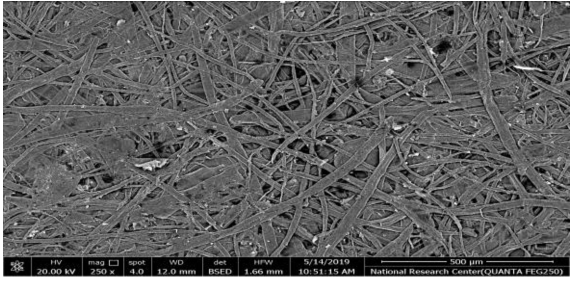
(b) Softwood



(c) Bagasse

Figure 8. scanning electron micrograph (SEM) of (a) Hardwood, (b) Softwood, (c) bagasse, x = 50µm

(a) 20 %SW+20% HW+60% BP



(b) 20% SW+80% HW

Fig 9. scanning electron micrograph (SEM) of (a) sample (20% SW+20 %HW+ 60%BP) and (b) sample (20%SW + 80%HW), x=500µm

IV Conclusion

In this study bagasse pulp was successfully replaced HW pulp in tissue paper industry at constant percent of SW to get optimum results according to tissue paper industry. It was observed that addition of bagasse pulp has some improvement on sheet properties which is benefit and success to replace HW pulp in tissue paper industry. It will reduce the importing of HW from outsourcing as bagasse pulp is local producing in Egypt. As shown in the results the bagasse pulp was used in different percent replacing HW. The optimum percent was (20 % SW + 20 % HW + 60 % BP). It gave the best results with the tensile (The best improvement was 10.15% in absence of enzyme and reached to 15.18% in presence of enzyme). It was observed that mixing with more bagasse increase the negative value of zeta potential in absence of additives (the properties of tissue paper is improved very near to zero). Addition of additives caused decreasing of the negative value of zeta potential. Wet tensile index was improved by addition of wet strength agent, the best results were obtained by the sample (20 % SW+ 80% BP), the improvement was 16.53%, and also the sample (20% SW + 20 % HW + 60 % BP) showed improvement of 13.4 %. Dry Strength showed improvement at the sample (20 % SW+ 20 %HW +60 % BP) reached to 10.15 % without Enzyme and 15.18 % with Enzyme adding. Smoothness showed improvement reached to 11.6 % by the sample (20 % SW+60 % HW+ 20 % BP) after addition of softener. From most results the best result was obtained at the sample (20%SW+20% HW+60% BP).

Bagasse pulp can be used as an alternative to HW in tissue paper industry with improvement in the final product propertie

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