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Effects of bagasse microfibrillated cellulose and cationic polyacrylamide on key properties of bagasse paper

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ABSTRACT

This study explores the benefits of using bagasse microfibrillated cellulose (MFC) in bagasse paper. Two different types of MFC were produced from DED bleached soda bagasse pulp. The MFC was added to soda bagasse pulp furnishes in different amounts. Cationic polyacrylamide (C-PAM) was selected as retention aid. The results show that addition of MFC increased the strength of paper as expected. Interestingly, 1% MFC in combination with 0.1% C-PAM yielded similar drainage time as the reference pulp, which did not contain MFC. In addition, the samples containing 1% MFC and 0.1% C-PAM yielded (i) a significant increment of the tensile index, (ii) a minor decrease of opacity and (iii) preserved Gurley porosity. Hence, this study proves that small fractions of MFC in combination with adequate retention aids can have positive effects with respect to paper properties, which is most interesting from an industrial point of view.

1. Introduction

Microfibrillated cellulose (MFC) is a promising biomaterial for use in bio-nanocomposites. MFC materials may be composed of nanofibrils, fibrillar fines, fiber fragments and fibers. Properly produced MFC materials contain a major fraction of nanofibrils (Chinga-Carrasco, 2011). This abundant nano-scaled fiber has a potential role in the production of bionanocomposites due to the low cost in comparison with other synthetic nanomaterials, the abundance of the raw materials and the environmentally friendly properties such as biodegradability and renewability.

Different technologies have been employed to produce MFC. The major mechanisms for MFC production are high mechanical shearing treatments *via* high pressure homogenizer (Henriksson, Berglund, Isaksson, Lindström, & Nishino, 2008; Turbak, Snyder, & Sandberg, 1983; Zimmermann, Bordeanu, & Strub, 2010), grinders (Taniguchi & Okamura, 1998) and cryo-crushing (Bhatnagar & Sain, 2005; Chakraborty, Sain, & Kortschot, 2005). In addition, research has been conducted on pretreatments such as enzymatic (Henriksson et al., 2008; Pääkkö et al., 2007) and TEMPO-mediated oxidation (Saito, Nishiyama, Putaux, Vignon, & Isogai, 2006) to facilitate the fibrillation and decrease energy demands during MFC production. It has been proposed that use of enzyme technology is preferred to chemical methods due to lower cost, its high selectivity and eco-friendly characteristics (Hassan, Hassan, & Oksman, 2011).

Wood has been the most used source for production of micro- and nanocellulosic fibers. However, fibers from annual crops such as flax, hemp, kenaf, sisal in addition to agricultural residues like sugar cane bagasse, wheat and rice straw has attracted interest due to their wide abundance, low-cost, availability and renewability (Siro & Plackett, 2010). Presently, these valuable lignocellulosic resources are either burned or used in biorefinery processes. Conversion of such agricultural waste into value-added materials is thus of high industrial interest.

Different studies have proposed MFC for enhancing the mechanical properties of composites and paper sheets (Ahola, Österberg, & Laine, 2008; Eriksen, Syverud, & Gregersen, 2008; Hassan et al., 2011; Taipale, Osterberg, Nykanen, Ruokolainen, & Laine, 2010; Turbak et al., 1983; Zimmermann, Bordeanu, & Strub, 2010). Addition of MFC to paper yields significant increase in the corresponding

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Table 1
Bleaching condition of soda pulp in DED sequences.

Stage	Bleaching conditions		
	D_1[a]	(E)[b]	D_2[c]
Chemical charge (wt%)	2.4	1.4	0.6
Pulp consistency (wt%)	10	10	10
Time (h)	1	1	2
Temperature (°C)	70	70	70

[a] D_1: 1st Chlorine dioxide step.
[b] E: NaOH extraction.
[c] D_2: 2nd Chlorine dioxide step.

tensile index, however the sheet drainage is impaired (Eriksen et al., 2008; Taipale et al., 2010). Cationic polymers have been used as a fixative for retention of MFC as well as for better suspension drainability (Taipale et al., 2010). Taipale et al. (2010) assessed different polymers as MFC and fines fixatives, considering also the corresponding effects on drainage and paper strength. The authors concluded that by the optimum selection of MFC and high molar mass cationic polyelectrolytes, paper strength can be improved without reducing the drainage efficiency. Derivatives of polyacrylamide (PAM) are widely used as aids for strengthening, retention, dewatering and dispersion (Roberts, 1996). Retention aids or flocculants are normally added before sheet making in order to improve the retention and drainage. Good retention of fines and fillers is of technical and economic importance (Bhardwaj, Kumar, & Bajpai, 2005). However, no studies have been published about the reinforcing capabilities of different types of soda bagasse MFC in combination with cationic polyacrylamide (C-PAM).

The objective of the present research work was to assess the effects of bagasse MFC on relevant properties of paper produced from soda bagasse pulp. The combination of C-PAM and MFC in paper was assessed with respect to structural, mechanical and optical paper properties, which is interesting from an industrial point of view.

2. Materials and methods

2.1. Raw materials

The semi-bleached soda bagasse pulp was kindly supplied by Pars Paper factory in Ahvaz, Iran. Bleaching was an ECF bleaching processes using two chlorine dioxide steps with intermediate extraction, *i.e.* the DED sequence (Table 1). The chemical composition of the bleached pulp was determined according to NREL/TP-51042618 (Sluiter et al., 2008) and viscosity measurements according to ISO standard 5351:2010(E). The degree of polymerization (DPv) was estimated from the Marke–Houwink–Sakurada equation: $DPv^{0.905} = 0.75[\eta]$ (Sihtola, Kyrklund, Laamanen, & Palenius, 1963).

2.2. Production of MFC

Considering that this study focuses on the application of MFC in the production of low cost bagasse paper, two relatively simple methods for producing MFC have been chosen, *i.e.* mechanical and with enzymatic pre-treatment.

2.2.1. Mechanical pre-treatment of pulp

The bleached soda bagasse pulp was used in its never dried form. The pulp was first disintegrated by a high shear mixer at 30,000 revolutions. The fibers were refined with a PFI mill according to ISO5264-2. This pulp was used as a starting material for production of MFC.

2.2.2. Enzyme-pretreated MFC

The method of Pääkkö et al. (2007) was followed for producing enzyme-pretreated MFC. In the enzymatic treatment 100 g (calculated as dry fiber) of the refined pulp was dispersed in 2.5 L phosphate buffer (pH7) with 0.17 μL mono-component endoglucanase (Novozyme 476, 5 ECU/μL) per gram fiber. The suspension was incubated at 50 °C for 2 h. The mono-component endoglucanase was denatured at 80 °C for 30 min. Further, the enzyme pretreated sample was washed with deionized water.

2.2.3. Fibrillation

The pre-treated pulps were homogenized using a Rannie 15-type 12.56 × homogenizer, operated at 1000 bar pressure. The pulp consistencies during homogenization were 1%. The MFC samples were collected after 5 passes and will be referred to as “UMFC” and “EMFC” for the mechanical and enzymatic produced MFC, respectively. A schematic representation of the methods applied for production of MFC is presented in Fig. 1. In this study two MFC qualities were thus produced and tested (Table 2).

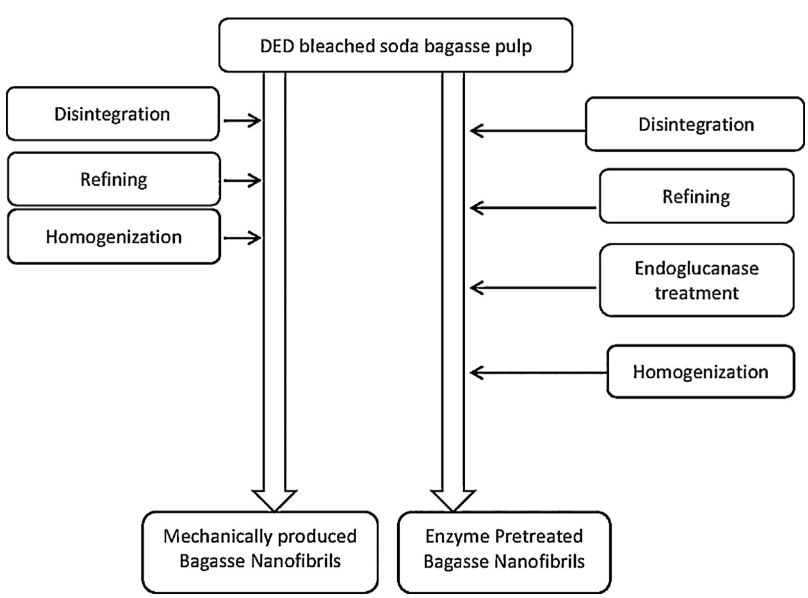

Fig. 1. Schematic representation of the processes applied for production of MFC from bagasse pulp.

Table 2
MFC from bagasse fibers produced in this study.

Abbreviations	Pretreatment	Homogenization (#pass)
UMFC	Refining	5
EMFC	Enzyme + refining	5

2.3. Pulp

Semi-bleached soda bagasse pulp having kappa number 12,was provided as never dried by Pars Paper factory in Ahvaz, Iran. This pulp was used for the hand-sheet production. The initial freeness of the pulp was 624 mL, CSF (Canadian Standard Freeness). The soda bagasse pulp was swollen, disintegrated and refined in a PFI mill according to the ISO 5264-2 standard and stored at approximately 10% (w/w). Impurities, such as remaining metal ions, were removed by hydrochloric acid treatment.

2.4. Cationic polyacrylamide (C-PAM)

Cationic polyacrylamide (C-PAM) was kindly supplied by Norske Skog in Norway in a concentration of 1.2%. C-PAM was diluted to a solution concentration of 0.05% 12 h before application. The C-PAM applied in this study was produced by NALCO EUROPE B.V in The Netherlands (product: NALCO® 74508) and had low charge density and high molecular weight properties.

2.5. Hand-sheet preparation

The MFC suspension (1% or 5% MFC) was added to the fiber suspensions. The resulting fiber/MFC suspensions were mixed for 20 min at 500 rpm before C-PAM (0.1 or 0.3%) was added. After 20 min of additional mixing at 500 rpm, hand-sheets were formed in a laboratory sheet former, with closed water circulation (ISO 5269-1:2005). The series of hand-sheets produced with varying amounts of MFC and C-PAM are given in Table 3. The target grammage including MFC was 60 g/m^2. The hand-sheets were produced according to ISO 52697/1-1979(E) and further air-dried in a climate room. The standards used for conditioning and physical, mechanical and optical paper properties are given in Table 4.

2.6. Structural analysis

Films (20 g/m^2) were made for the UMFC and EMFC series (Table 2), for assessing the morphological properties of the produced MFC materials. The films were prepared by placing the given MFC suspensions in plastic Petri dishes. The films were allowed to dry at 23 °C. The morphology of samples UMFC and EMFC was assessed with a field emission SEM (FE-SEM). The applied microscope was a Zeiss Ultra field-emission SEM (Zeiss Ultra field-emission SEM, Carl Zeiss AG, Oberkochen, Germany). Samples of the MFC films (5 mm × 10 mm) were mounted on aluminum plates and coated with gold. The images were acquired at 100× and 30,000× magnifications. The acceleration voltage and working distance were 3 kV and 5 mm, respectively. Images were acquired applying the secondary electron detector. The nanofibril diameter was quantified based on the images acquired at 30,000× magnification. 50 random measurements were undertaken manually.

FE-SEM Images of the hand-sheets were acquired with a Hitachi SU-6600 microscope. Samples of 5 mm × 10 mm were cut, placed on aluminum plates and coated with a layer of gold. The images were acquired in secondary electron imaging mode at 200×, 1000× and 5000× magnification. The acceleration voltage and working distance were 5 kV and 10 mm, respectively.

Table 3
The series of hand-sheets produced with different amounts of MFC and varying contents of C-PAM.

Codes	Soda bagasse (%)	MFC (%)	MFC quality	C-PAM (%)
SB	100	–	–	–
SBP1	99.9	–	–	0.1
SBP3	99.7	–	–	0.3
U1	99	1	UMFC	0
U5	95	5	UMFC	0
P1U1	99	1	UMFC	0.1
P3U1	99	1	UMFC	0.3
P1U5	95	5	UMFC	0.1
P3U5	95	5	UMFC	0.3
E1	99	1	EMFC	0
E5	95	5	EMFC	0
P1E1	99	1	EMFC	0.1
P3E1	99	1	EMFC	0.3
P1E5	95	5	EMFC	0.1
P3E5	95	5	EMFC	0.3

Table 4
Standards used for hand-sheet production and for measurements of physical, mechanical and optical properties.

Test methods	Standards
Closed water sheet making	ISO 5269-1:2005
Paper conditioning	ISO 187:1900
Laboratory wet disintegration	ISO 5263:1995
Determination of stock consistency	ISO 4119:1995
Freeness	ISO 5267-2:2001
Grammage	ISO 536:1995
Thickness and apparent density	ISO 534:1998
Air permeance (Gurley)	ISO 5636-5:2003
Tensile strength	ISO 1924-2:1994
Tear resistance	ISO1974
Opacity	ISO 2471
Brightness	ISO 2470
Light scattering coefficient	ISO 9416:1998

3. Results and discussion

3.1. Chemical compositions of raw material

The chemical composition of DED bleached soda bagasse pulp is presented in Table 5. As expected the amount of lignin is minor (≤0.5%). It is worth to note that the two major components are cellulose (glucose) and xylose, with fractions comparable to bleached pulp based on *e.g. Eucalyptus* (70% *Eucalyptus nitens* and 30% *Eucalyptus globulus)* (see Syverud, Chinga-Carrasco, Toledo, & Toledo, 2010). For comparison purposes, note that the xylan content of bagasse pulp is higher and the intrinsic viscosity and

Table 5
The chemical compositions, intrinsic viscosity and degree of polymerization (DP) of DED bleached soda bagasse pulp.

Properties		Bagasse	Eucalyptus
Chemical compositions (%)	Cellulose	73.3	79
	Xylose	25.3	20.3
	Arabinose	0.8	0.3
	Galactose	0.1	0.2
	Mannose	–	0.2
	Ash and residual Lignin	≤0.5	N.D.[a]
Intrinsic viscosity (mL/g)		576	890
Degree of polymerization (DP)		817	1321

[a] Not determined.

Table 6
The drainability, physical, mechanical and optical properties of hand-sheet produced from soda bagasse pulp with no MFC. The mean values are given with the corresponding ±1 standard deviation.

Properties/raw material	Drainage time (s)	Thickness (μm)	Tensile Index (N m/g)	Gurley (s/100 mL)	Tear Index (m N m²/g)	Opacity (%)
SB	10.3	94.4 (±3.8)	42.9 (±4.7)	243 (±20)	5.3 (±0.7)	74.4 (±0.4)
SBP1	9.8	93.5 (±2.3)	43.4 (±3.1)	272 (±18)	5.3 (±0.6)	74.1 (±0.4)
SBP3	11.2	92.2 (±1.3)	44.1 (±1.6)	312 (±32)	5.4 (±0.2)	73.8 (±0.6)

degree of polymerizationare lower than *Eucalyptus* and *Pinus radiata* bleached pulp fibers (see Syverud et al., 2010).

3.2. Hand-sheet properties of soda bagasse pulp

In order to assess the potential benefits of using combinations of MFC and C-PAM with respect to the properties of soda bagasse paper, the properties of standard hand-sheets composed of soda bagasse pulp and C-PAM without MFC will be used as references (Table 6).

3.3. MFC morphology

The morphological characteristics of the MFC qualities produced without and with enzymatic pre-treatment are shown in Fig. 2. The images reveal that the enzymatic pre-treatment has facilitated the fibrillation of the fibers. The sample EMFC has a minor fraction of poorly fibrillated fibers, compared to the UMFC sample. This is clearly evidenced in the images acquired at 100× magnification, which give a good overview of the fibers which are not fibrillated after the homogenization process. Although the enzymatic pre-treatment facilitated the fibrillation of a larger fraction of fibers, the nanofibril morphology does not differ significantly between the un-pretreated (UMFC) and enzymatic pretreated sample (EMFC) (Fig. 2, lower row). Quantification of the nanofibril diameters revealed diameters of less than 40 nm for both MFC qualities (UMFC and EMFC).

3.4. Hand-sheet structures composed of soda bagasse pulp, MFC and C-PAM

FE-SEM was used to qualitatively evaluate the hand-sheet structures. The reference sample, which does not have MFC, is shown in Fig. 3A. The visual assessment suggests that addition of MFC/C-PAM tends to smooth the surface and close the pores (Fig. 3B and C). It is worth to mention that such a structural development, which is a result of MFC addition, has been reported previously (Hii, Gregersen, Chinga-Carrasco, & Eriksen, 2012; Syverud, Gregersen, Chinga-Carrasco, & Eriksen, 2009). In addition, networks of nanofibril structures form between the fibers (Fig. 3B and C, right column).

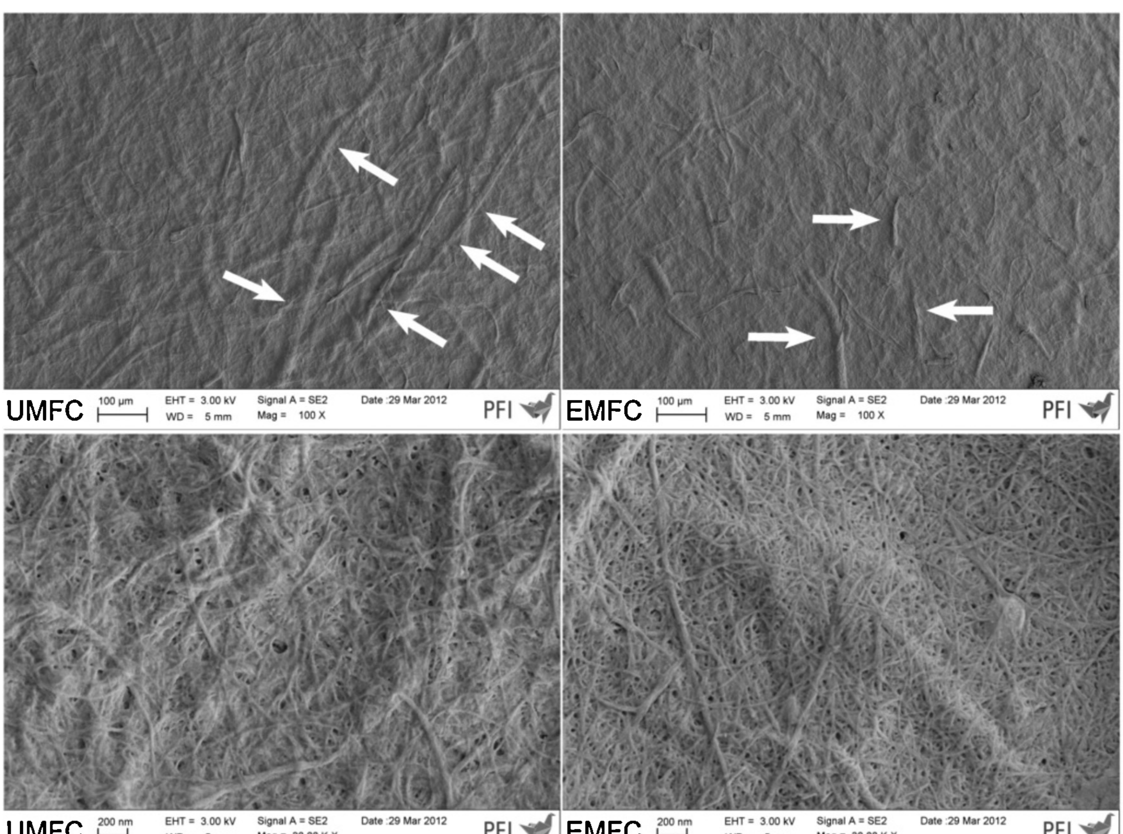

Fig. 2. FE-SEM analysis of MFC structures. UMFC: five passes un-pretreated bagasse MFC. EMFC: five passes enzyme-pretreated bagasse MFC. Upper row: images acquired at 100× magnification. The white arrows indicate poorly fibrillated fibers. Lower row: images acquired at 30,000× magnification, for closer visualization of nanofibrils.

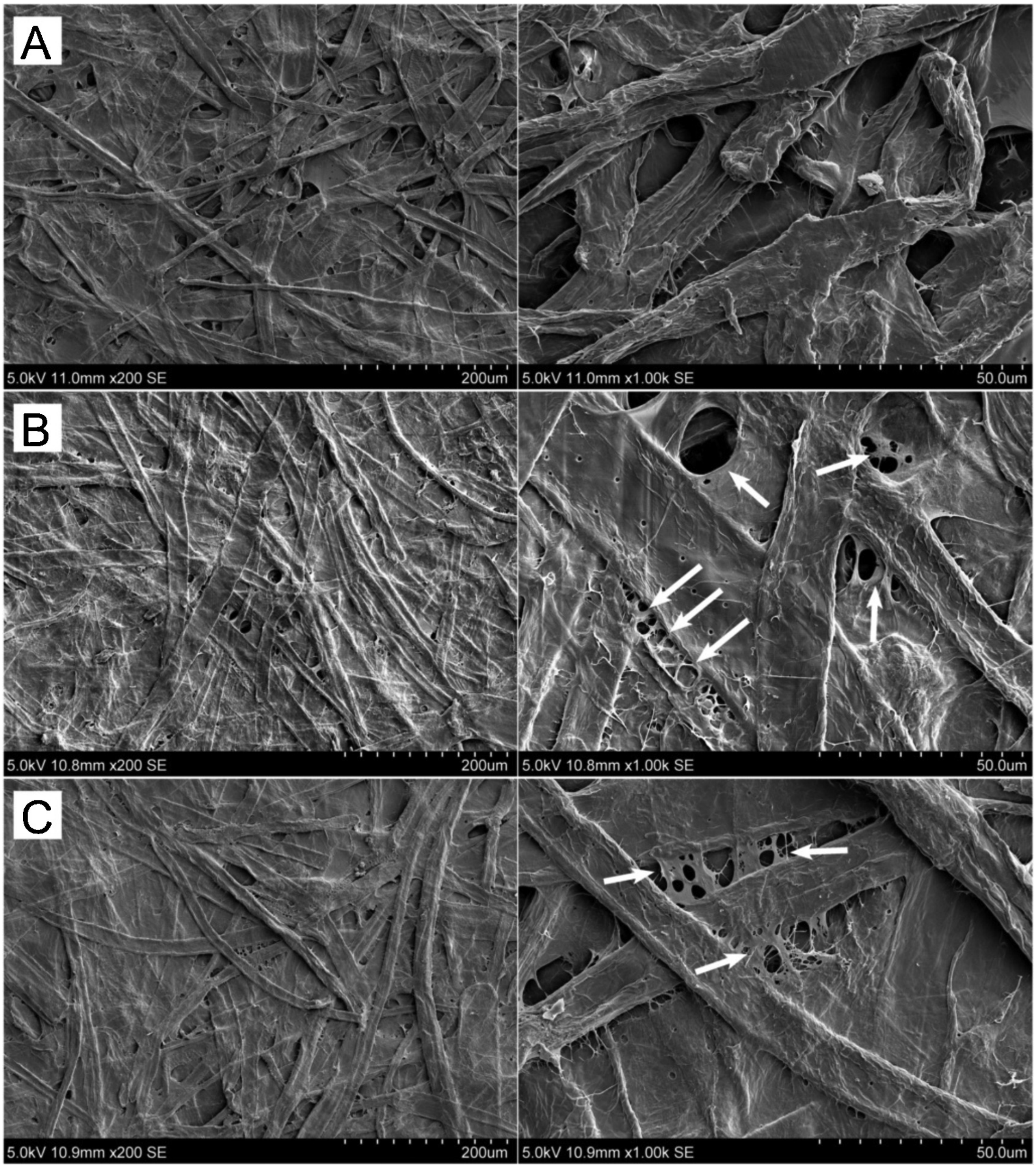

Fig. 3. FE-SEM analysis of sheet structures composed of soda bagasse pulp, MFC and C-PAM. (A) Soda bagasse paper with no MFC. (B) 5% UMFC, 0.3% C-PAM and 95% soda bagasse pulp. (C) 5% EMFC, 0.3% C-PAM and 95% soda bagasse pulp. The corresponding images acquired at 1000× magnification are presented in the right column. The white arrows indicate the additional bonding between fibers and nanofibril structures.

3.5. Drainage times

C-PAM was added to the paper furnish in order to study the effect of a cationic polymer on the drainage time. Addition of neat MFC in different amounts increased the drainage time of the suspensions considerably (Fig. 4a). Compared to the reference pulp (drainage time = 11.2 s, drainage times of 16 and 38 s were obtained with furnish containing 1% and 5% UMFC. However, application of C-PAM decreased the retention time of the suspensions which contained MFC. We have applied C-PAM in 0.1 and 0.3% based on oven dry pulp since Xiao, Salmi, Laine, & Stenius (2009) stated that the dewatering efficiency substantially deteriorated at doses higher than 0.4%. The authors also reported that the dewatering time decreased rapidly initially and then started to increase slowly with an increasing addition of C-PAM. The highest drainage time was 38.3 s for furnish containing 5% UMFC, while it was 23.7 s for the corresponding furnish with 0.1% C-PAM. The lowest drainage time (about 10 s) was achieved when 0.1% C-PAM and 1% EMFC or 1% UMFC was added to the pulp (Fig. 4a). This value was similar to the reference pulp (SBP1), indicating that 1% MFC can be used in the furnish of soda bagasse pulp without deteriorating the drainage time, which is a most interesting result. We have achieved the mentioned results with C-PAM having a low charge density and high molecular weight. The results are thus in agreement with Xiao et al. (2009), *i.e.* this type of C-PAM (see Section 2.4) had a good effect on drainability. It is worth to mention that Taipale et al. (2010) reported that by an optimum selection of high molecular mass polyelectrolyte, high paper strength can be achieved without loss of drainage efficiency.

This study demonstrates that adding low amounts of MFC (1%) does not increase the drainage time, provided that an adequate retention aid is added to the furnish (0.1% C-PAM). The drainage time can be related to the dewatering efficiency of the pulp in a paper making process, which in turn affects the energy required to

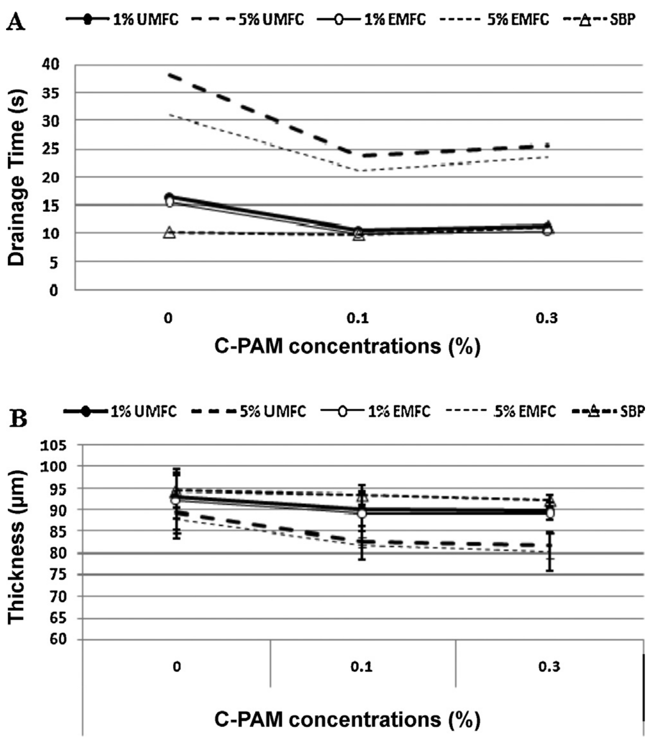

Fig. 4. The effect of different contents of MFC and varying percentage of C-PAM on the drainage time (A), thickness (B) of hand-sheets from soda bagasse pulp.

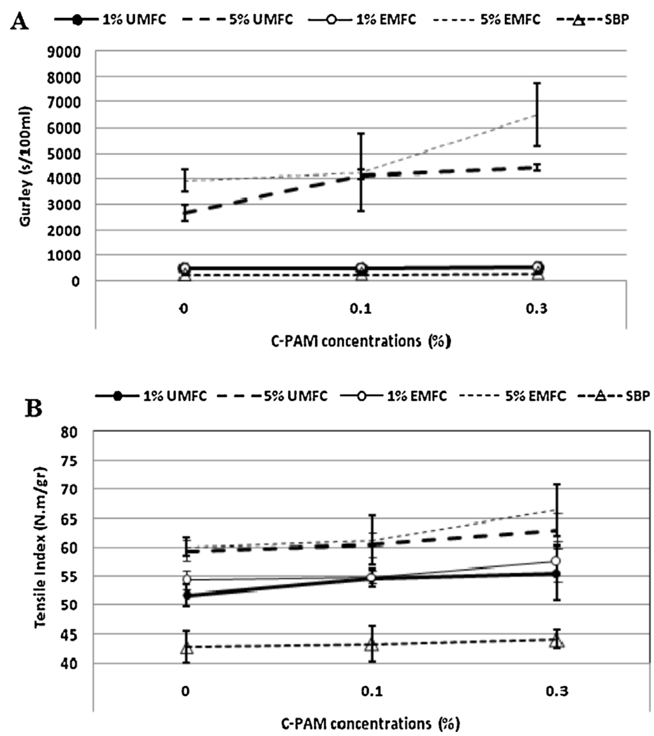

Fig. 5. The effect of different contents of MFC and varying percentage of C-PAM on the gurley porosity (A), tensile index (B) of hand-sheets from soda bagasse pulp.

press and dry a given furnish. Due to the high fibrillation degree and large surface area of MFC materials, MFC reduces the drainage efficiency (see *e.g.* Hii et al., 2012). Previous studies reporting improvements in the mechanical properties of MFC-containing bagasse paper applied large fractions of MFC (>10%) (Hassan et al., 2011). Such levels of MFC will be challenging in an industrial situation due to the high level of energy that would be necessary to dewater and dry the paper. It is therefore desirable to keep a low MFC fraction in order to limit a potential reduction of the dewatering efficiency during paper making. From this point of view, the mechanical and optical properties of the hand-sheets containing 1% MFC and C-PAM were considered most important to assess.

3.6. Physical properties

The thickness of the hand-sheets is presented in Fig. 4b. The thickness decreased with addition of 5% MFC, compared to the thickness of the reference sheet (93.5 μm, Table 6). Soda bagasse pulp as well as MFC are all anionic in neutral water (Salmi, Österberg, Stenius, & Laine, 2007; Taipale et al., 2010) and will thus repel each other (Taipale et al., 2010). The main reason for using C-PAM is that it is expected to bind fines and MFC material to the fiber structures through charge neutralization. The bridging of the stock suspension occurs before the fiber mat is formed (Forsberg & Strom, 1994; Norell, Johansson, & Persson, 1999; Scott, 1996). In the presence of C-PAM, the negative fines are partly neutralized, the double-layer forces are reduced and the fines start to flocculate (Xiao et al., 2009). As a result, the amount of bonds between fibers and nanofibrils increases. The sample containing 5% EMFC and 0.3% C-PAM was the thinnest, indicating that this paper had a more packed structure in comparison to the other hand-sheets. Compared to the SBP1 sample, addition of 5% MFC caused more than 8% reduction in thickness, irrespective of the MFC quality. It is worth to notice that the hand-sheets containing only 1% MFC do not have a major reduction in thickness. This implies that the bulk structure of the hand-sheets containing 1% MFC may have been preserved. Such assumption seems to be confirmed by the air permeability measurements. No difference was measured between the reference hand-sheet (SBP1) and the hand-sheets containing 1% MFC, irrespective of the dosage of retention aid. On the other hand, increasing the MFC fraction to 5%, decreased the air permeability considerably (higher Gurley measurement). This is most probably due to the compaction of the structures, which caused a decrease in porosity. This indicates that the pores between fibers are closed or reduced in size by the addition of 5% MFC (see Table 6 and Fig. 5a). Similar results have been reported by Hii et al. (2012).

3.7. Mechanical properties

3.7.1. Tensile index

As expected, addition of MFC significantly increased the tensile strength of the hand-sheets (Fig. 5b), which was promoted by the creation of bonding between fibrils and fibers (Fig. 7). The strength of the fiber network may also have been enhanced by the increased mechanical entanglement of the fibrils (See also Hii et al., 2012). Similar results have been reported previously (Ahola et al., 2008; Eriksen et al., 2008; Taipale et al., 2010; Hassan et al., 2011; Zimmermann et al., 2010). The positive effect of C-PAM is clearly demonstrated in Fig. 5b. Increasing the C-PAM fraction increases the tensile index. Samples containing 5% MFC yielded higher tensile index compared to the samples containing 1% MFC. Addition of 0.3% C-PAM increased the tensile index with about 22% and 40% for the sheets containing 5% UMFC and 5% EMFC, respectively. However, it is also worth to emphasize that addition of only 1% MFC increased the tensile index significantly.

The tensile index of paper remarkably increased with addition of MFC due to the high specific surface of MFC, the corresponding increased bonded area and the superior tensile properties of nanofibrils compared to fibers (Eriksen et al., 2008;

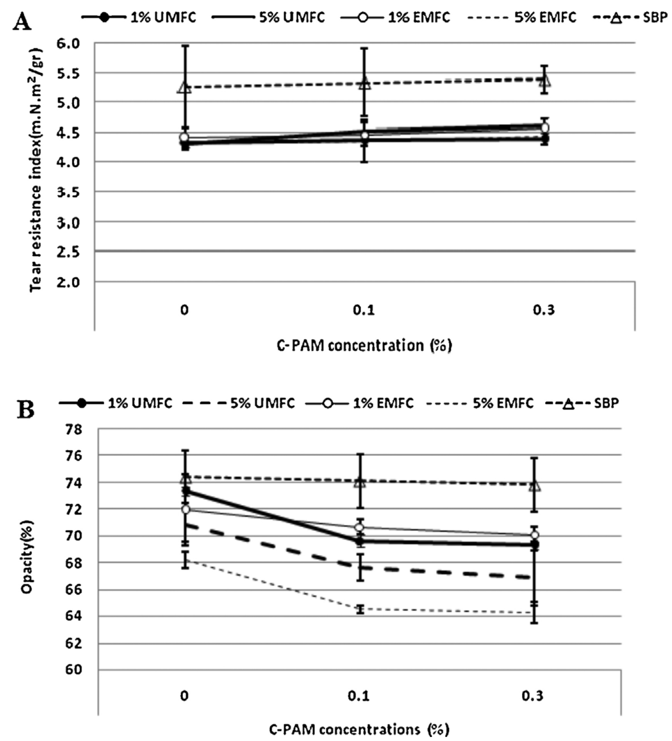

Fig. 6. The effect of different contents of MFC and varying percentage of C-PAM on the tear index (A) and opacity (B) of hand-sheets from soda bagasse pulp.

Henriksson et al., 2008; Hassan et al., 2011) made MFC-containing bagasse paper with various fractions of MFC (10–100%). Compared to the SB (with no MFC), the authors reported only slight increases of tensile index, with values between roughly 3 and 10 Nm/g, when using 10–100% MFC. It is worth to mention that in our study an increase of more than 11Nm/g was achieved when using only 1% MFC, which is a significant improvement. The relatively large increase is attributed to the highly fibrillated MFC material used in this study and the addition of C-PAM.

3.7.2. Tear index

Contrary to the tensile index, the tear resistance strength of paper was negatively affected by addition of MFC (Table 6, Fig. 6a). Hassan et al. (2011) reported that adding up to 30% MFC to bagasse pulp did not deteriorate tear resistance strength of paper sheets. However, Eriksen et al. (2008) have found that the tear index

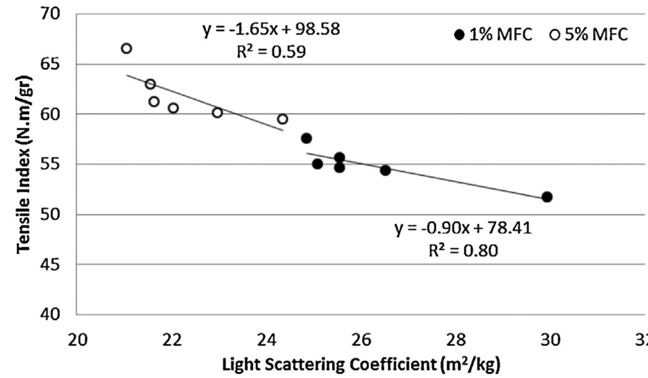

Fig. 8. Relationship between the light scattering coefficient and the tensile index for hand-sheets containing 1% and 5% MFC.

decreased by 3–10% when 4% MFC was added to the paper furnish, which is in agreement with the results obtained in our study.

3.8. Optical properties

By replacing 5% of the soda bagasse pulp fiber with MFC, the opacity decreased significantly. This reduction is related to the compaction of the sheet structure, which reduces the light scattering coefficient of the hand-sheets and consequently reduces the opacity. The lowest opacity value was 64.3% for the sample containing 5% EMFC and 0.3% C-PAM (Fig. 6.b), which is a significant reduction compared to 74.1% of the SBP1 reference (Table 6). However, adding 1% MFC caused only a slight reduction in opacity. This confirms the advantage of using a low dosage of MFC, which increased the tensile index considerably and caused only a slight decrease in optical properties.

The relationship between the light scattering coefficient and the tensile index is shown in Fig. 8. An increase in the tensile index is induced by an increase of fiber–fiber contacts. This in turn reduces the specific surface area and thus induces a decrease in the corresponding light scattering coefficient of paper, as explained by Mörseburg and Chinga-Carrasco (2009). Thus, hand-sheets containing 5% MFC had generally higher tensile index and lower light scattering, as expected (Fig. 8).

In this case, the total reduction of the light scattering coefficient for paper produced with a high amount of MFC, as well as C-PAM was 9% (P3E5 in comparison to SBP1). For comparison, Eriksen et al. (2008) reported that applying 4% MFC in paper decreased the light scattering coefficient by 4%. It is worth to mention that recent studies have demonstrated that a reduction of light scattering due to MFC addition may be counteracted by an addition of mineral fillers (Mörseburg & Chinga-Carrasco, 2009; Hii et al., 2012).

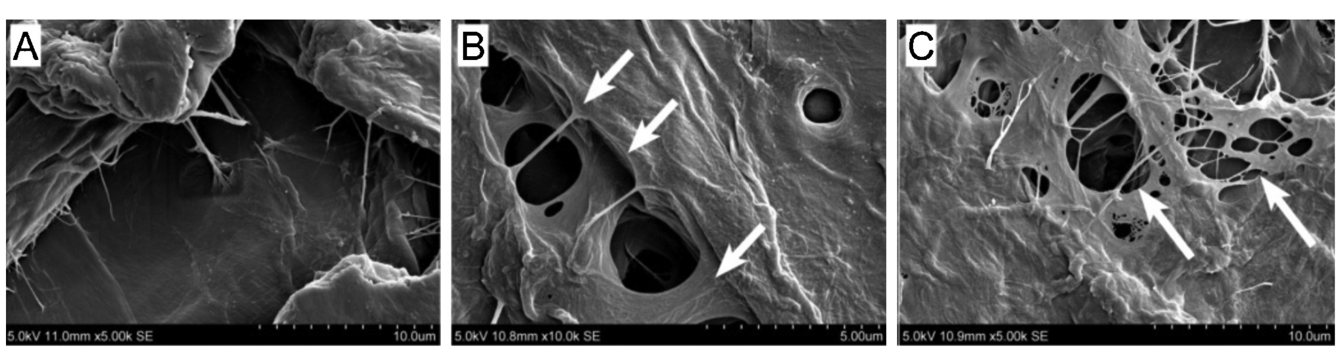

Fig. 7. Mechanical entanglement in hand-sheets produced from the reference sample (A), hand-sheet containing 5% UMFC (B), and hand-sheet containing 5% EMFC (C). The white arrows indicate the additional nanofibril structures which increase the binding between the fibers.

4. Conclusion

We demonstrated the effect of MFC and cationic polyacrylamide on key properties of hand-sheets based on bagasse pulp. 1% MFC with 0.1% C-PAM yielded similar drainage time as the reference pulp (SBP1), which did not contain MFC. In addition, our approach yielded (i) a significant increment with respect to the tensile index, (ii) a minor decrease of opacity and (iii) preserved Gurley porosity. Hence, this study proves that small fractions of MFC in combination with adequate retention aids can have positive effects with respect to paper properties, without affecting the drainage of the pulp, which is most interesting from an industrial point of view.

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