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The Performances of Cationic Starch (CS) And Sodium Carboxymethyl Celluloses (CMC-Na) As A Dry Strength Additives (DSA) On A4 Wastepaper

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Abstract. This study aims to identify the performances of cationic starch (CS) and sodium carboxymethyl celluloses (CMC-Na) as dry strength additives (DSA). The CS and CMC-Na were incorporated with to pulp slurry in different dosages (0.5% - 2.0%) during stock preparation. The basic weight of 80 g/m^2 was made for each treatment. The results showed that the utilization of CMC-Na had better mechanical properties compared to the CS for all treatments. In general, apparent density and mechanical properties were significantly affected by the addition of DSA. However, through the observation of the experiment, the enhancing effect of CMC-Na on mechanical properties of wastepaper was much higher than using CS except for tear strength. The FESEM imaging results can also help prove the best DSA used in wastepaper production.

INTRODUCTION

Paper industries are one of the most significant industrial sectors in the world. The manufacture of paper produces products such as newspapers, notebooks, magazine offices, catalog paper, tissue, glossy paper, and paper-based packaging. These all products are the most worlds product used in our daily life [1]. The increasing demand for wood-based materials for market paper products indirectly causes deforestation and harms the environment [2]. The insufficient to sustain papermaking usage of wood as raw materials and an alternative source have been introduced to replace the primary sources of wood in the pulp and paper industry [3]. Due to new world phenomena, collecting of wastepaper and processing them into raw materials and manufacturing new products using these recycled raw materials [4]. There are three types of recycled paper which are old corrugated cartons (OCC), newspaper or mechanical paper and wastepaper. The main focus of this research is a type of wastepaper. Wastepaper consists of office-grade paper, white-printing paper, and high-quality paper [5]. Some studies have been conducted to find the best solutions to replace wood-based materials with recycled paper as raw materials by adding adhesive to improve the properties of properties in recycled paper [5–10].

The adhesive was used in wastepaper production is dry strength additives (DSA) and wet strength additives that used to increase the performance of the paper products. DSA is classified as a type of starch cellulosic fiber [11] and used as one of the most significant chemical additives in the preparation of recycled paper products to increase the mechanical properties,

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paper strength, paper grades, and printing properties [5]. DSA is water soluble, hydrophilic natural and synthetic polymers. The addition of DSA can interact with fibers in several ways to enhance the paper strength, especially in the interaction of hydrogen bonding formation [12]. Moreover, it has been observed and suggested that DSA, such as starches, improves the performances on the bond strength between cellulosic fiber in recycle paper. Two types of DSA are used in this project which is sodium carboxymethyl cellulose (CMC-Na) and cationic starch (CS). CS and CMC-Na are used to strengthen the mechanical properties of the wastepaper product. Both additives greatly improve paper strength properties with attracted attention due to their easy availability and lower cost from pulping industries [10].

The objective of this case study intended to investigate the performances of CS and CMC-Na on structural and mechanical properties of paper produced from wastepaper. In this study, the paper was made by blending wastepaper pulp with the addition of DSA at a different dosage. Overall pulp and paper characteristics tests were conducted according to the Technical Association of the Pulp and Paper Industry (TAPPI) and Malaysian ISO (MS ISO) standards. Therefore, the response variable evaluated in this study included structural properties (grammage and apparent density) and mechanical properties (tear strength, tensile strength, and burst strength). The blended paper morphologies are investigated using field emission scanning electron microscope (FESEM).

MATERIALS AND METHOD

Raw Material

A4 wastepaper used as raw material was supplied by Sanisa Book center, Pontian, Johor. Two type of DSA (CMC-Na and CS) were kindly supplied by Antik Sempurna Sdn. Bhd.

Preparation of Laboratory Paper Making and Characterization

The laboratory paper (80 g/m^2) was prepared according to the TAPPI T-205 sp-02 “Forming Handsheets for Physical Tests of Pulp”. Meanwhile, paper properties were characterized according to the Malaysian Standard Methods (MS ISO). For the papermaking, the pH of stock preparation was maintained between 5.5 and 6.5. In order to access the potential benefits of using CMC-Na and CS with the properties of blending paper, one set of wastepaper without DSA was used as control paper and properties. Various solutions of CMC-Na and CS, in dosages of 0%, 0.5%, 1.0%, 1.5% and 2% based on o.d. weight of recycled pulp were added during stock preparation.

Before paper formation, the paper machine opened, and the wire surface was cleaned away from adhering fibers by water. The machine was closed, and water was added until it filled the machine to half of its depth. The diluted recycled pulp stock (1000 mL) was poured into the paper machine. Then, the slurry was mixed with the perforated and stirred by rapidly moving up and down five times. After mixing, the drain cock of the machine was opened to release the water under suction. The paper machine was opened, and three blotting papers were placed on the drained paper. The brass flat couch plate was then laid down, and the brass couch roll was placed gently in the middle of the plate. The roll was rotated forward and backward 5 times. The paper was thereafter removed from the wire screen, covered with three blotting papers and a metal plate, and pressed at 275 kPa for 10 minutes to further remove excess water. Then, the two blotters against each other were changed and the same pressure was applied for additional 5 minutes. Next, each plate with its attached paper was then fixed into the pile of standard rings. A heavy-weight metal block was placed on the ring stack to restrain the paper's edges during drying. Finally, the hand stack papers were conditioned at 23 oC ± 1 oC and 50% ± 2.0% RH (T 402 sp-03) for at least 24 hours prior to testing. Eight papers were used for test their physical properties such as Grammage (MS ISO 287: 1985, IDT), Thickness (MS ISO 534: 2005, IDT), Tensile Strength (MS-ISO 1924-2: 2008, IDT), Bursting Strength (MS ISO 2758: 2001, IDT) and Tearing Strength (MS ISO 1974 : 1990, IDT).

Paper Morphology

The wastepaper samples were cut into small pieces 3 mm long and 3 mm wide. The fiber surface and fracture section morphology in the wastepaper samples were observed using a field emission scanning electron microscope (FESEM) at various magnifications (250 X -1500 X). The specimen was attached to aluminum stubs with double-sided carbon adhesive tape and coated with gold before the examination using FESEM.

Statistical Analysis of Paper Characteristics

One-way analysis of variance (ANOVA) was employed to examine the significant effects of each factor of structural and mechanical properties of wastepaper for each treatment on the response variables in this study (paper characteristics). The treatment score means were compared using Turkey's Group Range Test (P≤0.05) at 95% confident level using Minitab R.19.2 software.

RESULTS AND DISCUSSION

Structural and strength properties

Basically, apparent density is a structural property and used as a predictor of paper strength, since fiber bonding in the paper increases both strength and density [13]. It can be simply calculated from the grammage and thickness of paper. The apparent density also characterized by a fine fiber [14]. In general, fine fibers improved sheet consolidation and bonding formation because of their large specific surface area. The control paper has an apparent density value of 0.371 g/cm^3. The addition of DSA attributed to the increasing of wastepaper performances of density significantly for CMC-Na dosage 0.5% to 2.0% with the value of 0.358 g/cm^3 to 0.422 g/cm^3 (Table 1).

TABLE 1. Effect of blending wastepaper properties at different dosages of DSA

Paper Properties	0%	0.5%	1.0%	1.5%	2.0%
Structural properties					
Thickness (µm) - CMC-Na	231.13 ^{a} (±11.25)	223.54 ^{ab} (±2.80)	216.58 ^{bc} (±7.43)	199.49 ^{e} (±4.54)	180.91 ^{f} (±2.32)
Thickness (µm) - CS		212.4 ^{abc} (±4.42)	212.16 ^{cd} (±5.52)	205.77 ^{de} (±7.15)	198.32 ^{e} (±6.91)
Apparent Density (g/cm^3) - CMC-Na	0.371^{cd} (±0.03)	0.358 ^{d} (±0.04)	0.372 ^{cd} (±0.01)	0.399 ^{b} (±0.01)	0.442 ^{a} (±0.01)
Apparent Density (g/cm^3) - CS		0.361 ^{d} (±0.01)	0.337 ^{bcd} (±0.01)	0.389 ^{bc} (±0.01)	0.397 ^{b} (±0.02)

* Means with same letters in column are not significantly different at the (P≥0.05)
*± = Standard deviation

Tearing, tensile, and bursting strength were the most important characteristics of paper. Statistically, some results were found to be different between the parameters being assessed. The graph illustrated in Figure 1 shows the results of the tear index vs. DSA dosage (%). The series of DSA were 0.5, 1, 1.5, and 2.0 (%). The comparison was made with the two types of DSA, which are CMC-Na and CS.

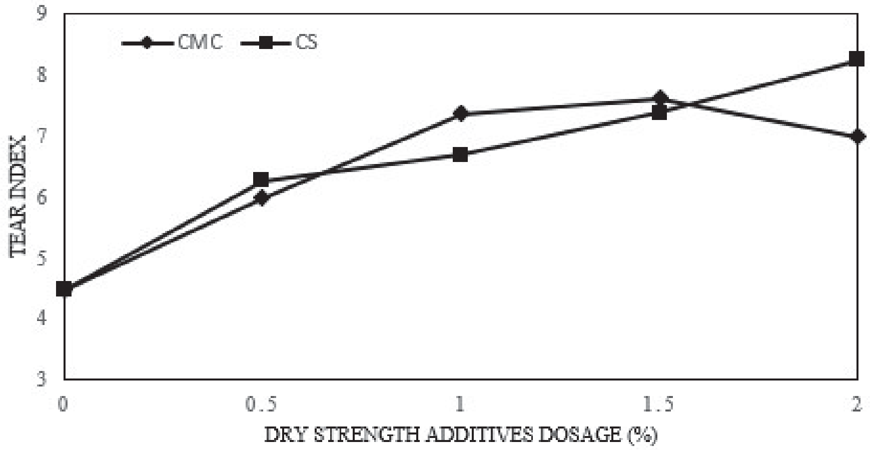


FIGURE 1. Tear index at different dosage (%) of DSA

As seen in Figure 1, the tear index readings increased slightly as the dosage of DSA increased. For CMC-Na, the tear index value was increased by almost 26.6% at a 1.5% dosage of DSA and start decrease with the addition of CMC-Na/2.0. Meanwhile, the highest dosage of using CS made the highest reading of tear strength with the value of 8.23 mNm2/g at CS/2.0. This proves that performances of CMC-Na in tear strength are limited at a dosage of 1.5% only. The tearing test is susceptible to the physical or structural properties of the fiber [15]. The important factors affecting tear strength are fiber length and inter-fiber bonding. Longer fibers naturally provide more points of bonding and are pulled a longer average distance from the network [16].

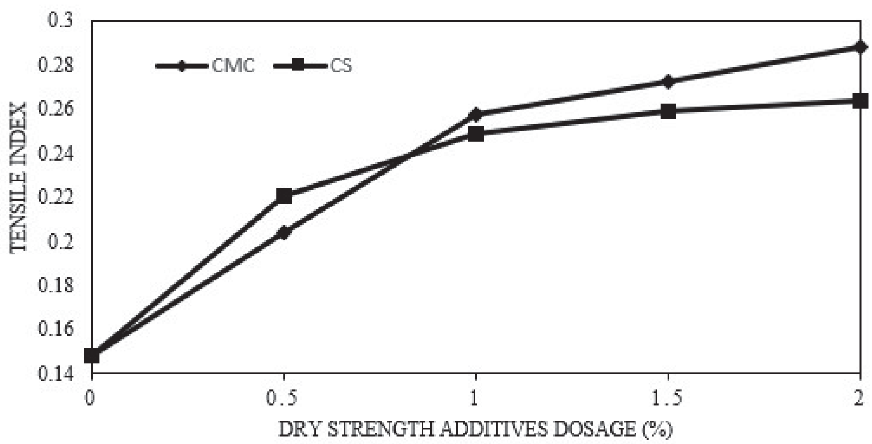


FIGURE 2. Tensile index at different dosage (%) of DSA

Tensile strength is one of the basic strengths tested on a paper. According to the ANOVA analysis, the tensile strength for treated samples is generally higher than in the control sample. As expected, adding CMC-Na and CS significantly increased the tensile strength of the blending wastepaper (Figure 2), especially samples containing CMC-Na, which was promoted by more or increased creation of fiber bonding.

As seen from Figure 2, the addition dosage of 2.0% of pulp treated with CMC-Na had the highest tensile strength (0.288 N.m/g) compared to the same condition used of CS in the pulp slurry (0.264 N.m/g). The tensile strength of the paper is independent of chemical properties and is very much dependent on the bonding ability of the fibers in the networks [17]. Based on a previous study, the sample containing 0.5% of aPAM and cPAM, the increase in tensile strength was about 8% and 7%, respectively, more than the control sample [12]. From this study it is also shown that both DSA improve in tensile strength at a minimum dosage of 0.5%.

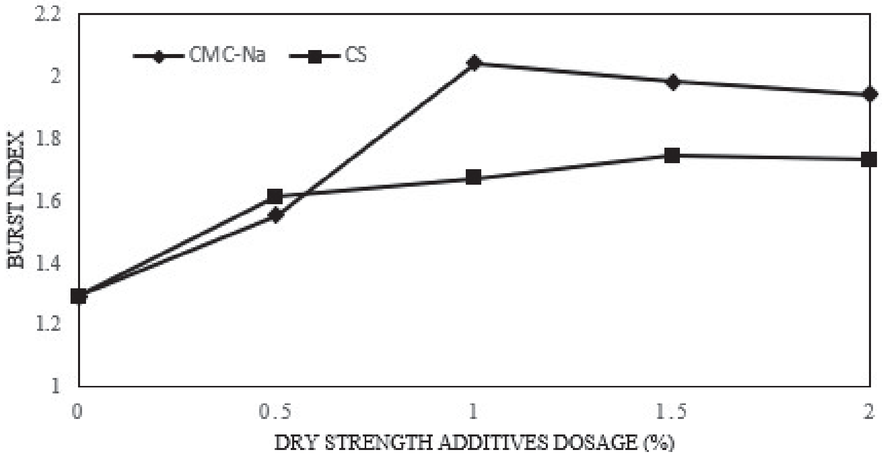
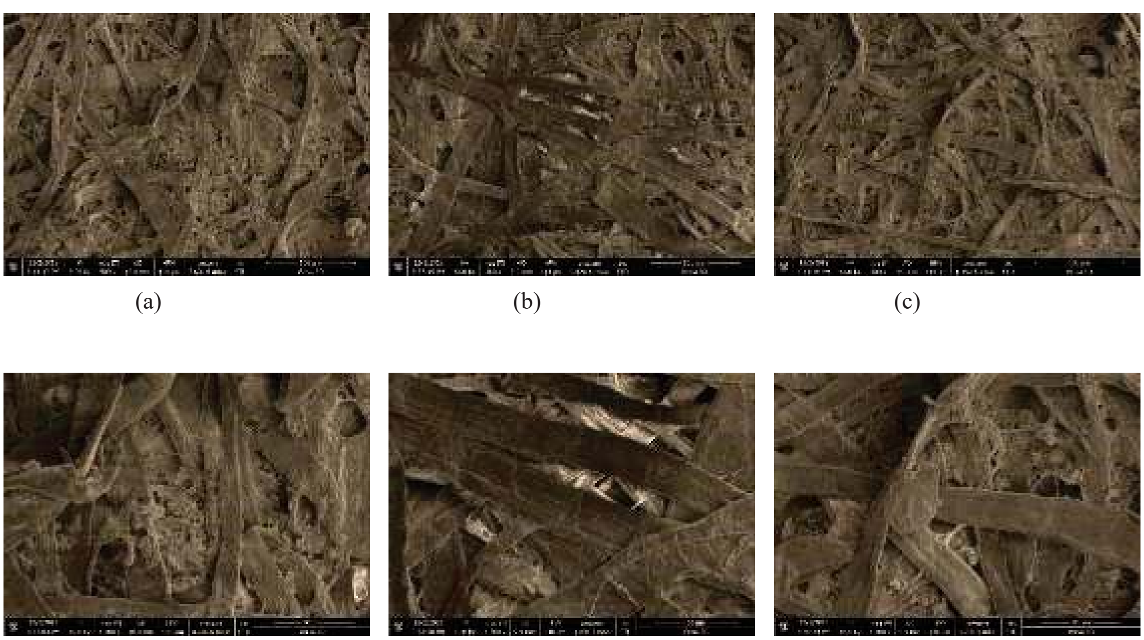


FIGURE 3. Burst index at different dosage (%) of DSA

Based on Figure 3, a paper sample of CMC-Na/1.0 has a burst strength of 2.06 kPa m2/g, which was the highest value in this investigated parameter. Meanwhile, for CS, the dosage of 1.5% was the highest burst index with a value of 1.74 kPa m2/g. An increase in the burst strength was observed when CMC-Na and CS were initially added to the stock preparation before the value decreased with the higher dosage (CMC-Na/1.0 and CS/2.0).

Field emission scanning electron microscopy (FESEM) Image Analysis

The surface morphology of the wastepaper was investigated by using FESEM. The FESEM imaging for the control condition, CMC-Na/1.0, and CS/1.0 were examined. Figure 4 shows the comparison between 3 samples with 500X and 1500X magnification.



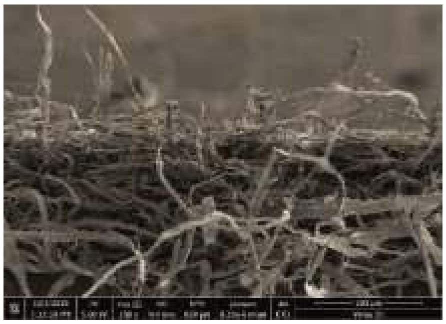
(a) (b) (c)

(d) (e) (f)

FIGURE 4. (a – c) Image of surface morphologies of control 1.0% CMC-Na and 1.0% CS at 500X magnification. (d - f): Image of surface morphologies of control, 1.0% CMC-Na and 1.0% CS at 1500X magnification

The fiber arrangements were not straight and had some kinds and crimps. The control condition wastepaper showed more voids than the 1.0% dosage of CMC-Na and CS. This occurs because of inter-fiber bonding after the addition of DSA.

Wastepaper fracture cross-sectional morphology for CMC-Na/1.0 and CS/1.0 with 250X magnification and 500X magnification are shown in Figure 5. The sample used for identified paper cross-sectional is from the tearing test. According to Van den Akker [18], tearing work is composed of two different phenomena, the work of breaking the fibers and the frictional work pulling them out of the undamaged network. Tearing strength is strongly influenced (positive correlation) by fiber strength, probably because the long fibers are very pliable and entangled at many points and can distribute stress over a wide area. The fracture inter-fiber bonding shows that the presence of DSA increases the strength of the fiber in the wastepaper..



(a)

(b)

(c)

(d)

FIGURE 5. (a – b) Image of fracture cross-sectional morphologies of control 1.0% CMC-Na and 1.0% CS at 250 X magnification. (c – d): Image of fracture cross-sectional morphologies of control 1.0% CMC-Na and 1.0% CS at 500 X magnification

CONCLUSION

This study investigated and obtained the performances of CS and CMC-Na as a DSA on the A4 wastepaper. Several conclusions were drawn from the result analysis. The addition of different dosages of DSA increased the apparent density and tensile strength of pulp, especially for CMC-Na. The tensile strength shows a positive reaction along with the addition of DSA. For the tear strength, the addition of DSA dosage ranging from (0.5% - 2.0%) was improved significantly in a wastepaper blending sample compared to the control sample. Meanwhile, a higher dosage (1.5% - 2.0%) of CMC-Na and CS did not contribute significantly to further improvement of the burst strength. The morphology analysis showed that CMC-Na and CS have a positive effect on inter-fiber bonding compared to the control sample.

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