Effects of the Size and Distribution of Preflocculated GCC on the Physical Properties of Paper

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ABSTRACT

Increasing the filler content of sheet improves the optical properties and printability of paper and provides an opportunity for saving production cost through fiber replacement with relatively low-priced filler. But increasing the filler content tends to decrease the strength of paper and filler retention. It also tends to deteriorate drainage on the paper machine. To overcome these problems, preflocculation technology of fillers may be employed. Many research efforts have been made on the properties of preflocculated filler, namely prefloc, whose size and size distribution were influenced by polymer type and shear level. But there is much to be investigated about the effect of the prefloc characteristics on the physical properties of paper. To evaluate the effect cationic polymers on the size and size distribution of preflocculated GCC and their shear stability, cationic PAM and cationic starch were used. The influence of the preflocculation on filler retention and its surface distribution, and the changes of physical and optical properties of handsheets affected by the characteristics of preflocs were examined. Filler distribution on sheet surface was also analyzed by EPMA. Results showed that cationic PAM formed large preflocs at low dosage. Cationic starch was required to add 15 times as much as cationic PAM to obtain the preflocs with similar size. But preflocs formed with cationic starch was superior in shear stability to those formed with cationic PAM. Filler preflocculation technology could provide an opportunity of increasing filler content significantly without loss in tensile strength. And increased filler contents could compensate brightness loss which often accompanies filler preflocculation. When excessively large preflocs were used, however, brightness loss rather than the improvement in tensile strength was predominant. Therefore it is of great importance to produce preflocs with proper size and shear stability for maximizing the improvement of physical properties of papers.

INTRODUCTION

Papermakers wish to increase the filler level in fine papers because it affords a number of advantages. One of the most important of advantages is an opportunity for saving production cost through fiber replacement with relatively low-priced filler. Furthermore, increased filler content of sheet improves the optical and printing properties of paper. Also ease of drying of filler because of its low affinity for water can provide an opportunity of reducing steam consumption in dryer section.

However, fillers also have unwanted effects on paper properties and papermaking processes. The drawbacks of filler in paper properties are mainly associated with the loss of bonding between fibers. Increasing the filler content tends to decrease many strength properties of paper including tensile strength, folding endurance, burst strength, internal bond strength, stiffness, etc. Also diverse problems associated with printing properties such as linting and dusting may results with the increase in filler content of paper. Increase in filler content in papermaking stock causes greater chemical consumption and poor retention which causes two-sidedness of the paper. It also tends to deteriorate drainage on the paper machine. Furthermore, abrasion on the paper machine can increase. Such diverse disadvantages of increasing filler content often limit the papermakers to increase filler content while using conventional retention systems. To overcome these problems, preflocculation of fillers may be employed (1). Several research efforts on the properties of preflocculated filler, commonly called prefloc, have been made. For instance, the size and size distribution influenced by polymer type and shear level was investigated by Mabee and Harvey (2). It has been suggested that the properties of preflocculated fillers need to be optimized to obtain highest possible filler retention, machine performance, and physical sheet properties (3, 4).

But there is much to be investigated about the effect of the prefloc characteristics on the physical properties of paper.

In this study, to evaluate the effect cationic polymers on the size and size distribution of preflocculated GCC and their shear stability, cationic PAM and cationic starch were used. The influence of the preflocculation on filler retention and its surface distribution, and the changes of physical and optical properties of handsheets affected by the characteristics of preflocs were also examined.

EXPERIMENTAL

Raw materials

Bleached hardwood kraft pulp was beaten to 450 mL CSF in a laboratory Valley beater. The filler used in this work was ground calcium carbonate with a mean particle size of 1.545 μm and a zeta-potential of -17.6 mV (Hydrocarb 75F, Korea Omya Co.). Cationic PAM and starch were used as preflocculating polymer. The properties of these polymers are shown in Table 1. Polymer viscosities used were measured with a Brookfield viscometer (RV, No. 2 spindle).

Table 1. Properties of cationic polymer

	Viscosity (cPs at 0.5%, 25°C)	Charge density (meq/g at pH 7)
C-PAM	137.5	1.37
C-starch	280.0	0.32

Evaluation of the prefloc size and its distribution

Prefloculation of filler was carried out in a filler mixing cell shown in Fig. 1, which is similar to the dynamic drainage jar. While the GCC slurry at a solids content of 20% was agitated in the filler mixing cell, a cationic polymer was added and stirred for 30 seconds. And then the prefloc size and size distribution was evaluated.

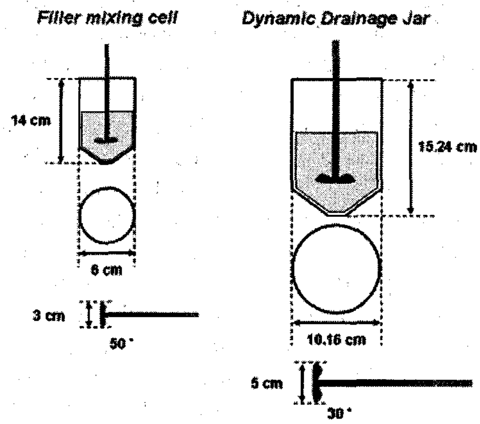


Fig. 1. Filler mixing cell and DDJ.

To obtain flocculated fillers with different particle size and size distribution the stirring speed of the filler mixing cell and the addition level of cationic polymers have been adjusted. The prefloc size and its size distribution were measured using a particle size analyzer from Malvern (Master Sizer 2000, Malvern Instrument Co.). The volume weighted mean sizes of preflocs were derived from the curves of prefloc size distribution. The volume weighted mean was simply denoted as the prefloc size and its standard deviation was expressed by the size distribution.

Handsheet studies

Handsheets were produced to a target basis weight 90 g/m^2 using an experimental handsheet former. The addition level of filler ranged from 20% to 50% at an interval of 10%. No other chemical additives except preflocculating cationic polymers have been used. In the case of preflocculation experiment, the cationic polymer was added to the filler slurry. Then the preflocs were taken and mixed with fiber stock before forming handsheets. The handsheets were pressed at a pressure of 3.5 kg/cm^2 and dried on a drum dryer at 120°C. Paper conditioning and testing were carried out in accordance with the relevant TAPPI Test Methods. Some handsheets were made following the conventional procedure. In this case the cationic polymers were added to the stock samples containing pulp fibers and fillers. Flow diagrams for forming handsheets are depicted in Fig. 2.

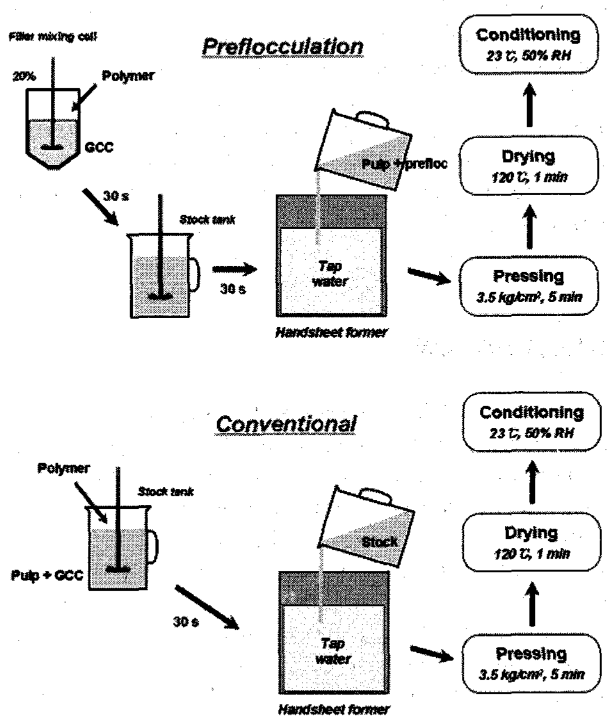


Fig. 2. Flow diagrams for forming handsheets.

The filler distribution on the sheet surface

The distribution of fillers on the surface of a handsheet was examined with the use of an electron probe X-ray microanalyzer (EPMA) (5). The surface distribution of GCC filler used in this work was described by detecting calcium (Ca-Kα X ray) element on the paper surface. The color identification of the concentration profile was made and displayed as a color map (6).

RESULTS AND DISCUSSION

Evaluation of the prefloc size and its distribution

Preflocculated fillers with various size and size distribution were formed by varying the addition level of the cationic polymer and shear level. Fig. 3 shows the particle size distribution curve of the GCC before flocculation. The mean particle size of GCC was increased after flocculating with 0.02 ~ 0.06% of C-PAM and 0.8% of C-starch (Fig. 4 ~ Fig. 7). With the increase of agitation speed of the filler mixing cell from 1000 rpm (1k) to 3000 rpm (3k), the particle size of preflocculated GCC decreased rapidly. Table 2 shows the mean size and standard deviation of prflocs. The St. Dev. indicates the standard deviation of prefloc and it indirectly represents the particle size distribution of preflocculated GCC.

Table 2. Mean particle size and standard deviation of preflocculated GCC under various conditions

Polymer dosage		1000 rpm	2000 rpm	3000 rpm
C-PAM 0.02%	Mean size (μm)	114	52	25
	St. Dev.	277	133	67
C-PAM 0.04%	Mean size (μm)	170	95	62
	St. Dev.	393	199	144
C-PAM 0.06%	Mean size (μm)	266	166	84
	St. Dev.	462	306	159
C-starch 0.8%	Mean size (μm)	345	141	96
	St. Dev.	410	179	124

Table 2 shows that addition of cationic PAM produced quite large prefloc at low dosage. It was required to add cationic starch at an addition rate 15 times greater than that of cationic PAM to obtain the same size preflocs. But the prefloc formed with cationic starch showed narrower size distribution and it was superior in shear stability to those formed with cationic PAM. Table 3 shows the influence of cationic polymers and stirring speed on the reduction of mean size and standard deviation of preflocs.

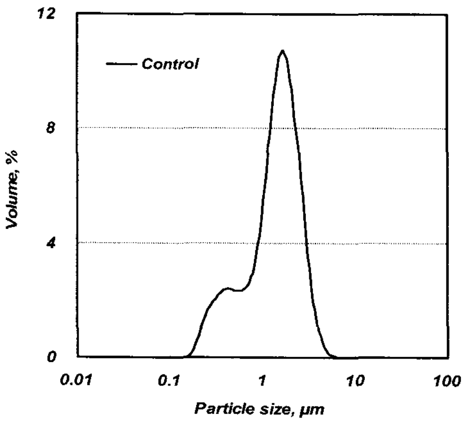


Fig. 3. Size distribution curve of GCC.

Table 3. Reduction of mean size and standard deviation of prefloc as a function of agitation speed.

Polymer dosage		2000 rpm	3000 rpm	Reduction (%)
C-PAM 0.06%	Mean size (μm)	166	84	49.4
	St. Dev.	306	159	48.0
C-starch 0.8%	Mean size (μm)	141	96	31.9
	St. Dev.	179	124	30.7

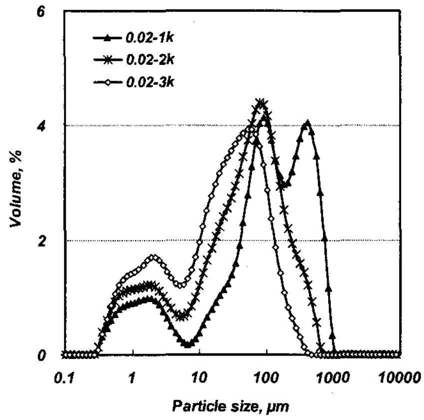


Fig. 4. Size distribution curves of preflocculated GCC after flocculating with 0.02% of C-PAM at various agitation speeds. (agitation speed / 1k : 1000 rpm, 2k : 2000 rpm, 3k : 3000 rpm)

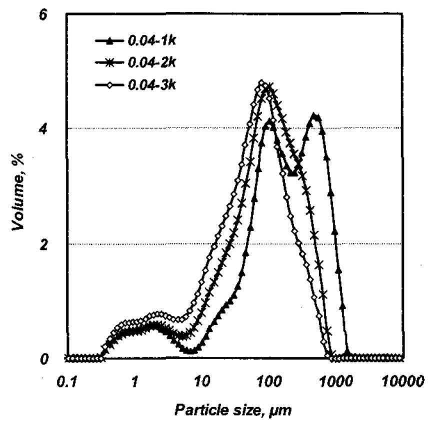


Fig. 5. Size distribution curves of preflocculated GCC after flocculating with 0.04% of C-PAM at various agitation speeds.

Handsheet studies

In order to investigate on the effect of the prefloc characteristics on the physical properties of paper, filler retention, tensile strength and brightness of handsheets were determined. The filler retention was evaluated by measuring the ash content of handsheets. Fig. 8 depicts the relationship between the filler loading and final ash contents in the paper web formed by preflocculating the GCC with 0.06% of C-PAM at various agitation speeds.

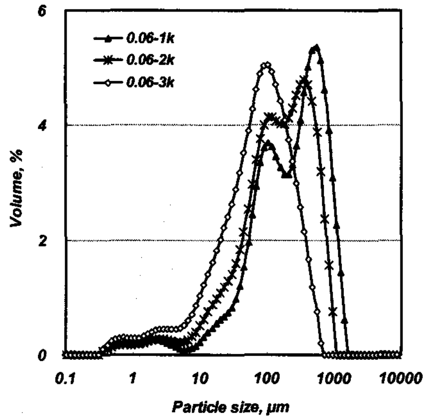


Fig. 6. Size distribution curves of preflocculated GCC after flocculating with 0.06% of C-PAM at various agitation speeds.

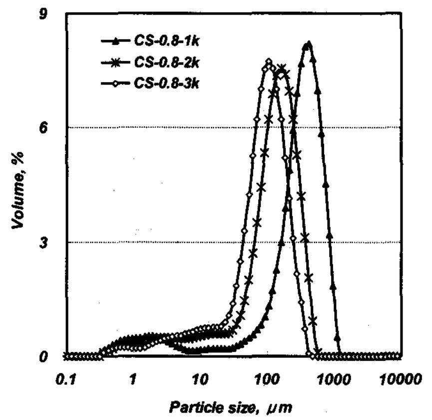
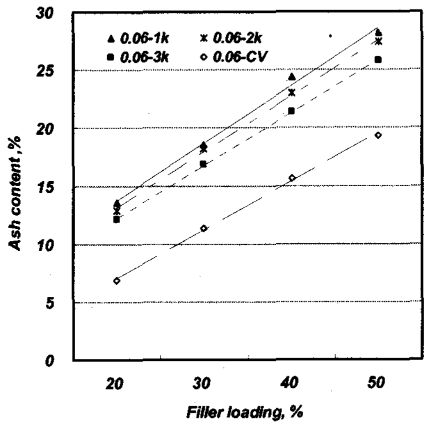


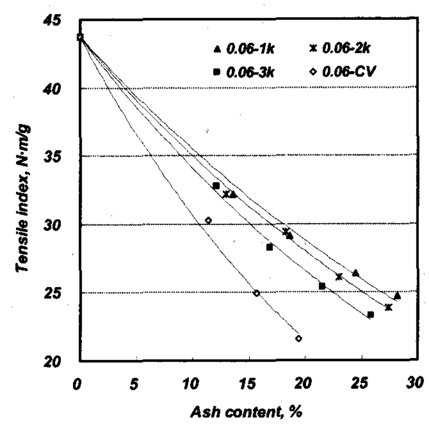
Fig. 7. Size distribution curves of preflocculated GCC after flocculating with 0.8% of C-starch at various agitation speeds.

Filler preflocculation system generally gave better retention than conventional system. Filler retention increased slightly when the agitation speed decreased. This indicates that the size of prefloc was one important factor for filler retention.

The tensile strength and brightness of handsheets as a function of ash contents of handsheets were depicted in Figs. 9 and 10. The amount of cationic PAM addition was kept constant at 0.06% while three different stirring speeds were employed in this experimentation. These data show that increasing the size of preflocculated GCC improved tensile strength of handsheets. Brightness of handsheets, however,



decreased as the size of preflocculated fillers increased. This shows that perflocculation of GCC results in less disruption of fiber-fiber bonding and improves in tensile strength. Consequently, filler preflocculation technology could provide



an opportunity to increase filler content with less reduction in tensile strength compared with the conventional filler loading method.

Fig. 8. Ash content as a function of filler loading after flocculating with 0.06% of C-PAM at various agitation speeds. (CV : conventional)

Fig. 9. Tensile index of handsheets as a function of ash content. 0.06% of C-PAM was used for preflocculation.

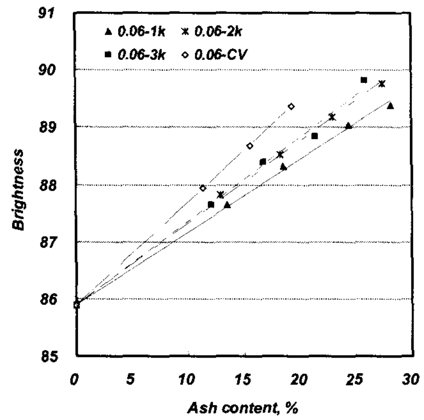


Fig. 10. Brightness as a function as a function of ashe content. 0.06% of C-PAM was used for preflocculation.

Brightness improvement with ash content was a bit reduced due to decreases in light scattering effects of preflocculated filler agglomerates. The loss in brightness associated with filler preflocculation may be compensated by increasing the level of ash content. This shows that preflocculation of fillers can be employed as a method to decrease the tensile strength loss with the increase of filler content in papers.

To investigate the effect of mean prefloc size on the physical properties of paper, three different combinations of C-PAM addition and stirring speed were employed as shown in Table 4. Preflocs of GCC with mean sizes ranging from 25 μm to 166 μm were prepared and used in handsheet forming. Fig. 11 shows that larger prefloc gave higher retention of fillers. Figs. 12 and 13 show tensile index and brightness of handsheets as a function of ash contents. Preflocs with larger diameter gave greater tensile index. When the mean size of preflocs increased excessively, however, no further improvement in tensile index was obtained.

Table 4. Conditions of evaluating the physical properties of handsheets

	0.02%, 3000 rpm	0.04%, 2000 rpm	0.06%, 2000 rpm
Mean size (μm)	25	95	166
St. Dev.	67	199	306

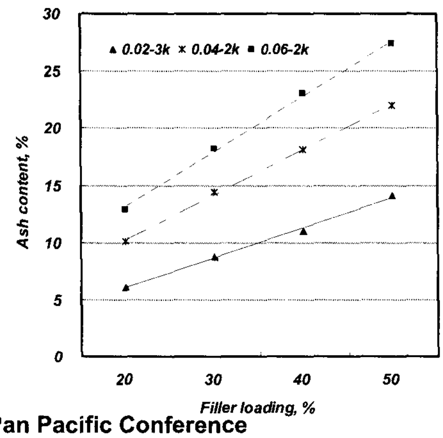


Fig. 11. Ash content as a function of the loading of preflocs with different mean sizes (Table 4).

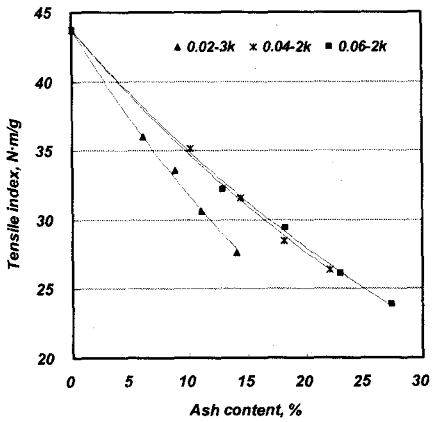


Fig. 12. Tensile index as a function of ash content for preflocs with different mean sizes (Table 4).

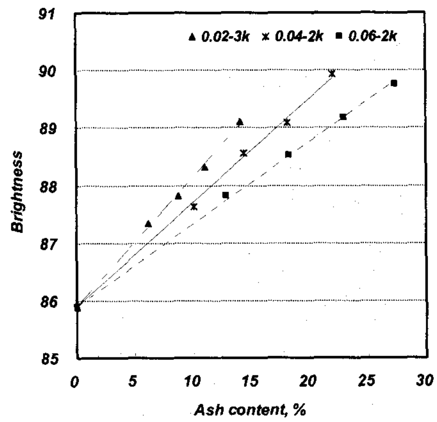


Fig. 13. Brightness as a function of ash content for preflocs with various mean sizes (Table 4).

When excessively large preflocs were used, brightness loss rather than improvement in tensile strength was predominant. This suggests that there is an optimum range of mean particle size to obtain most benefits of using preflocculation method.

The filler distribution on the sheet surface

The filler distribution on sheet surface was analyzed by EPMA. Figs. 14, 15 and 16 are EPMA Ca maps on sheet surfaces that contained similar amount of ash. Fig. 14 shows the Ca map of handsheets formed by a conventional method. Figs. 15 and 16 are Ca maps of handsheets containing preflocculated GCC. The bright part of EPMA Ca map indicates the presence of Ca element. More uniform distribution of GCC fillers were obtained when conventional filler loading was employed. Preflocculation of GCC with cationic polymer resulted in agglomerated fillers with large mean sizes and this was reflected in EPMA maps in Fig. 15 and 16. Table 5 shows the ash content and brightness of the handsheets shown in Figs. 14~16.

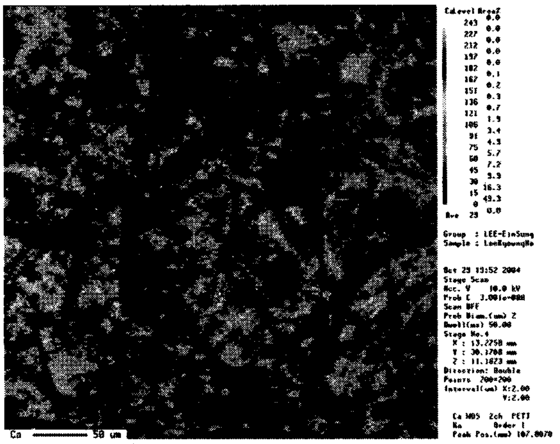


Fig. 14. EPMA Ca map of sheet surface prepared by conventional method.

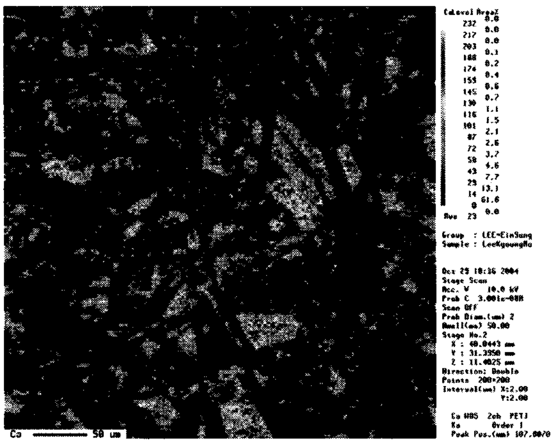


Fig. 15. EPMA Ca map of sheet surface with preflocs formed with 0.04% C-PAM at 2000 rpm of agitation speeds.

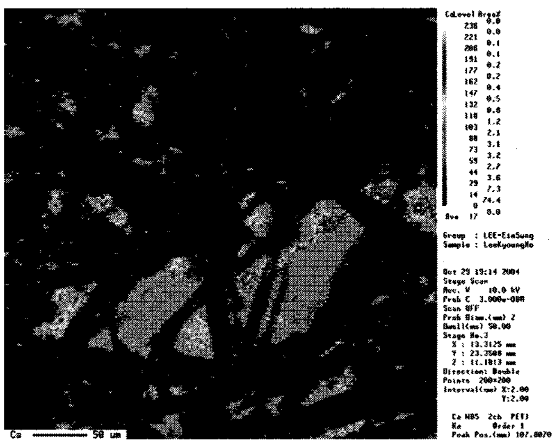


Fig. 16. EPMA Ca map of sheet surface with preflocs formed with 0.06% C-PAM at 1000 rpm of agitation speeds.

Table 5. Prefloc mean size, ash content and brightness of Figs. 14 ~ 16

	0.04%, CV	0.04%, 2000 rpm	0.06%, 1000 rpm
Mean size (μm)		95	266
Ash content (%)	15.3	13.6	14.4
Brightness	89.0	88.6	87.6

CONCLUSIONS

Filler preflocculation technology could provide an opportunity to increase filler content significantly without loss in tensile strength. And increased filler contents could compensate brightness loss which often accompanies filler preflocculation. When excessively large preflocs were used, however, brightness loss rather than improvement in tensile strength was predominant. Therefore it is of great importance to produce preflocs with proper size and shear stability for maximizing the improvement of physical properties of papers via preflocculation.

ACKNOWLEDGEMENT

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