Improvement in the Retention and Strength of Paper Made from White-grade Wastepaper

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White ledger is white-grade recycled pulp that replaces the bleached kraft pulp (BKP) that typically forms the top ply of duplex boards. However, sheets made from white ledger are inferior in strength compared with those made from virgin pulp. Therefore, it is necessary to select a proper additive in order to overcome the disadvantages of using white ledger. In this study, the physical properties of white ledger used at a mill that produced duplex boards were analyzed. The effect of cationic polyacrylamides (C-PAMs) with different charge densities and molecular weights on first-pass retention and paper strengths was simultaneously measured. White ledger contains fiber fines and filler fines, which reduced the strength of paper made from white ledger compared with paper made with BKP. This indicates that the improvement of first-pass retention and paper strength is important when the amount of white ledger increases in the top ply of a duplex board. The charge density of C-PAM, which acts as a retention aid, is more important than its molecular weight in terms of improving the first-pass retention and paper strength of white ledger. The charge density of C-PAM must be high enough to catch anionic fine particles.

Keywords: White ledger; Duplex boards; Recycled pulp; Cationic PAM; Retention; Strength

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INTRODUCTION

Recycled pulp is an important raw material used in paper products. The use of recycled pulp has increased globally in recent years (Ibarra *et al*. 2012). Recycled pulp from old newspapers (ONP), old corrugated containers (OCC), old magazines (OMG), white ledger, and mixed office wastes (MOW) is widely used in the manufacture of paperboard. The production of paperboard accounts for 50% of the paper products created by the Korean paper industry.

Duplex boards or white lined chipboards are used to package food, pharmaceuticals, detergents, textiles, clothing, and more (Kiviranta 1997). Wood powder and other organic fillers have been added to the middle ply of duplex boards to reduce production costs in Korean duplex board mills (Lee *et al.* 2014a; Park *et al.* 2015). Reducing the use of virgin pulps is the first step toward lowering production costs and protecting domestic environments in Korea. The replacement of virgin pulp with recycled pulp is beneficial to the Korean paper industry and to the domestic environment.

A duplex board is typically made of many plies. The top ply generally consists of bleached kraft pulps (BKP), white ledger, and ONP. Other plies are made of recycled pulp of lower quality (Kiviranta 1997). Though the ratio of BKP is lower than that of other recycled pulp in the top ply of a duplex board, BKP must be replaced with white-grade recycled pulp to reduce production costs. White ledger consists of general office paper that is non-glossy and is either printed or unprinted; this office paper may include typing paper, copy machine paper, or white notebook paper. The production of white ledger has increased steadily as various printing technologies have developed. White ledger, which is of high quality in terms of its white color, brightness, and strength, contains a higher portion of chemical pulp and a lower content of recycled materials compared with other recycled pulp (Lee *et al*. 2015). However, the quality of white ledger has decreased because papermakers have increased the use of high-yield pulp (Zhai and Zhou 2014) and inorganic fillers (Jung and Seo 2015) in general office paper to reduce production costs. The high ash content of other recycled pulp has reduced the yield of raw materials and paper strength (Zhao *et al.* 2008). Therefore, it is necessary to improve the first-pass retention and paper strength of duplex boards that are made from white ledger and that have high ash content.

This study explored the ideal conditions of cationic polyacrylamides (C-PAMs) to improve the retention and strength of white ledger stock. The properties of white ledger used at an actual mill of duplex boards were analyzed and compared with the properties of recycled pulp from the same mill. Next, the first-pass retention of white ledger stock was measured by adding six types of C-PAMs with different charge densities and molecular weights. After determining first-pass retention values, the handsheets were constructed, and their strength was measured.

EXPERIMENTAL CONDITIONS

Materials

Pulp slurries were collected from the Kleannara mill (Cheongju, Korea) where six-ply duplex boards were produced. The pulp was classified as either recycled pulp or virgin pulp, both of which were used for the manufacture of duplex boards. The recycled pulp included white ledger, ONP, and OCC. The virgin pulp consisted of mixed BKP, which combined softwood BKP and hardwood BKP at a ratio of 5:5. Bleached chemo-thermo mechanical pulp (BCTMP) was also included.

Because C-PAMs were used as dewatering agents at the Kleannara mill, C-PAMs were selected as the retention aid in the white ledger line. However, a conventional C-PAM does not react well with increases in white ledger in the top ply line. Therefore, six types of C-PAMs were obtained from Songkang Industrial Co., Ltd. (Eumseongkoon, Korea), and their charge densities and molecular weights are shown in Fig. 1.

Methods

Analysis of the properties of recycled pulp and virgin pulp

The pulp slurries were obtained from the machine chests of stock preparation lines. The initial consistencies of the pulp slurries were measured and diluted to 1.0% using tap water. The pulp properties, including freeness (TAPPI T227 om-09 2009), ash content (TAPPI T244 cm-99 1999), and fines content (TAPPI T261 cm-10 2010) were measured. The average fiber length was also measured using a fiber analyzer (Kajaani FiberLabV.3, Metso, Finland).

The handsheets were prepared from recycled pulp and virgin pulp. After handsheets with grammages of 100 ± 4 g/m^2 were produced, the sheets were wet-pressed at 3.5 kg$_f$/cm^2 for 5 min using a laboratory wet press and dried at 120 °C using a cylinder dryer. The dried handsheets were conditioned at 23 °C and 50%

relative humidity (RH) to control the moisture content of the handsheets at 8%. The physical properties of the handsheets were determined, which included bulk (TAPPI T411 om-10 2010), breaking length (TAPPI T494 om-06 2006), burst index (TAPPI T403 om-10 2010), and compressive strength (TAPPI T818 cm-07 2007).

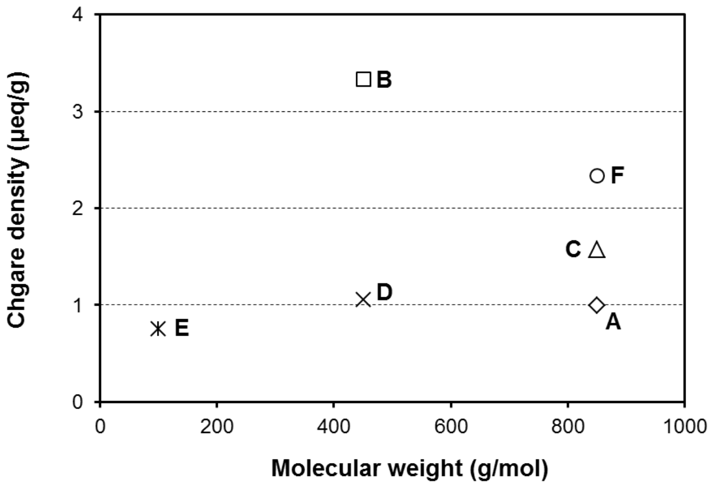

Fig. 1. C-PAMs as functions of molecular weight and charge density

Measurement of the first-pass retention of white ledger stock

First-pass retention was measured in terms of TAPPI T261 cm-10 (2010). The white ledger stock was diluted to 0.5% using tap water. Next, the C-PAMs were diluted to a concentration of 0.1% with distilled water. Then, 500 mL of the diluted white ledger stock was added into a dynamic drainage tester (Daeil Machinery, Daejeon, Korea) and stirred at a rate of 600 rpm for 30 sec. C-PAMs were added at the same mixing speed. The filtrate was collected from the stock after 90 sec. The filtrate was weighed, filtered, and dried at 105 °C to achieve a stable weight. Equation 1 was used to calculate first-pass retention,

$$\text{First pass retention} = \left[1 - \frac{A \times W}{U \times T}\right] \times 100 \qquad (1)$$

where A is the weight of the original sample, W is the weight of the solids (fines) in the filtrate, U is the weight of the filtrate, and T is total amount of fines in the sample.

Preparation of handsheets with white ledger stock and the measurement of their physical properties

White ledger stock was diluted using tap water to a consistency of 0.5% to prepare the handsheets. Handsheets with grammages of 100 ± 4 g/m^2 were produced according to TAPPI T205 sp-06 (2006), after the C-PAMs were added to the pulp and mixed for 30 sec at 600 rpm. The addition levels of C-PAMs were 0.03, 0.05, and 0.07% of oven-dried fibers. The handsheets were wet-pressed at 3.5 kg$_f$/cm^2 for 5 min using a laboratory wet-press and were dried at 120 °C for 4 min using a cylinder dryer. The dried handsheets were conditioned at 23 °C and 50% RH to control the moisture content of the handsheets at 8%. The physical properties, including the bulk (TAPPI T411 om-10 2010), breaking length (TAPPI T494 om-06 2006), burst index (TAPPI T403 om-10 2010), compressive strength (TAPPI T818 cm-07 2007), and ash content (TAPPI T244 cm-99 1999) of the handsheets were measured.

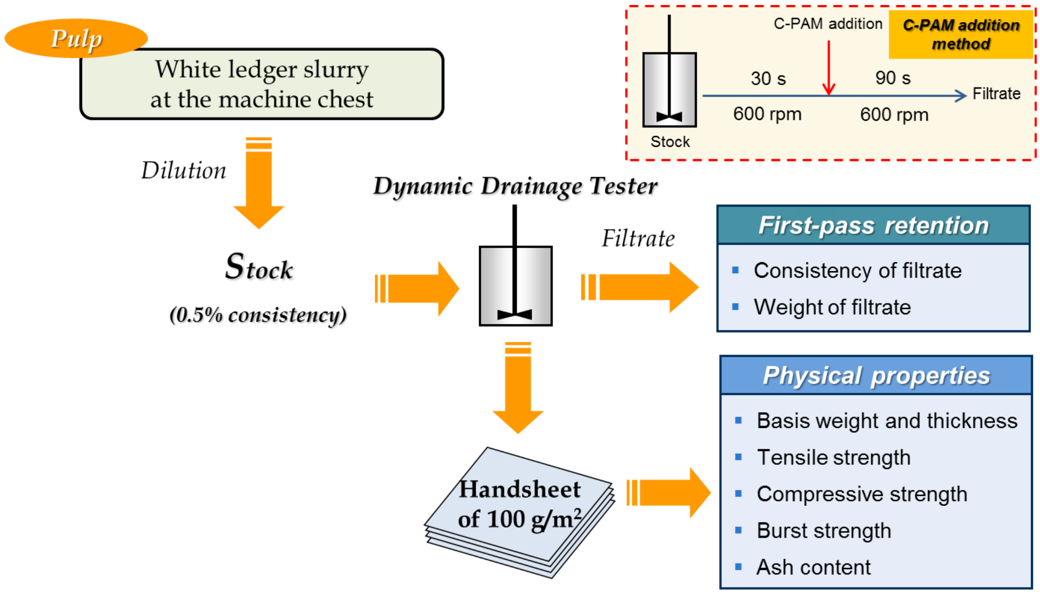

Fig. 2. Flow diagram of the experimental process

RESULTS AND DISCUSSION

Pulp Properties of Recycled and Virgin Pulp

The pulp properties of recycled and virgin pulp are shown in Figs. 3 and 4. The Canadian standard freeness of white ledger was lower than that of OCC and that of virgin pulp, but the freeness of white ledger was higher than that of ONP. The fines content of white ledger was higher than that of virgin pulp but lower than that of ONP and OCC. The average fiber length of white ledger was the lowest of the six types of pulp, and its ash content was the second lowest among the five types of pulp. White ledger contains more fine particles (such as fiber fines and filler fines) than BKP. This indicates that papermakers should monitor the yield or retention of fiber fines and filler fines when the amount of white ledger increases in the top ply of a duplex board.

Figures 5 and 6 show the physical properties of the handsheets, which consist of recycled and virgin pulps. The bulk of the white ledger handsheets was similar to that of the OCC and ONP handsheets, and lower than that of the BCTMP and BKP handsheets (Seo *et al*. 2014). The strength of the white ledger handsheets was greater than the strength of ONP and OCC. However, the strength of the white ledger handsheets was lower than the strength of the BCTMP and BKP handsheets. The low strength of the white ledger handsheets in comparison with those made exclusively with virgin pulp is directly related to its low average fiber length (Retulainen *et al*. 1997) and high ash content (Kroguerus 1997; Lee *et al*. 2014b). In addition, the changes in the fiber properties reduced the paper strength during the recycling process (Hubbe *et al*. 2007; Gulsoy *et al*. 2013).

The white ledger slurry produced handsheets that were lower in strength compared with BKP handsheets. The slurry contained fillers, pigments, and short fibers. Therefore, it is necessary to improve the first-pass retention and paper strength of white ledger handsheets. However, improving first-pass retention tends to result in increased ash content in sheets made from white ledger. Therefore, it is very important to select a proper retention aid that improves both first-pass retention and paper strength.

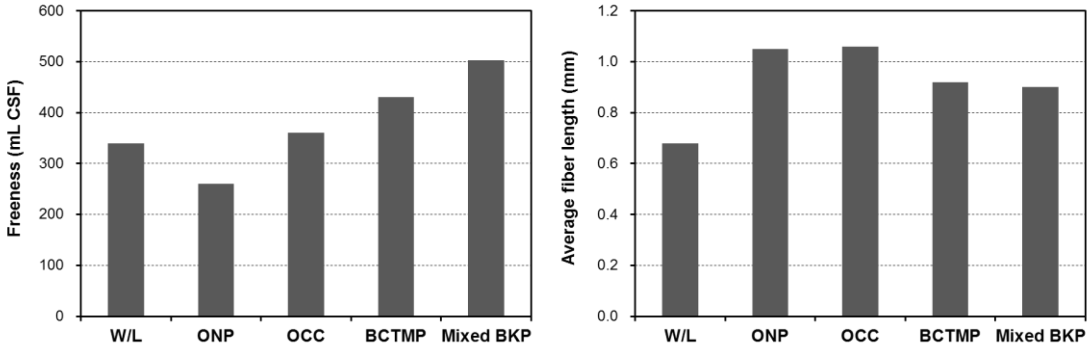

Fig. 3. Freeness (left) and average fiber length (right) of recycled and virgin pulp (W/L = white ledger)

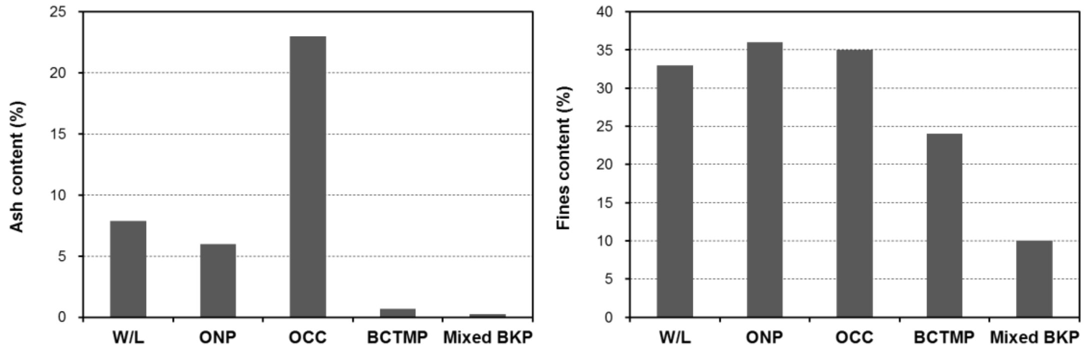

Fig. 4. Ash content (left) and fines content (right) of recycled and virgin pulp (W/L = white ledger)

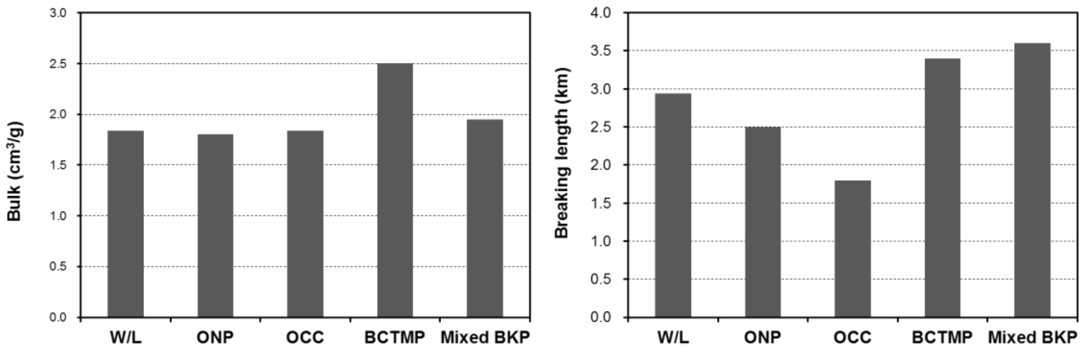

Fig. 5. Bulk (left) and breaking length (right) of handsheets made from recycled and virgin pulp (W/L = white ledger)

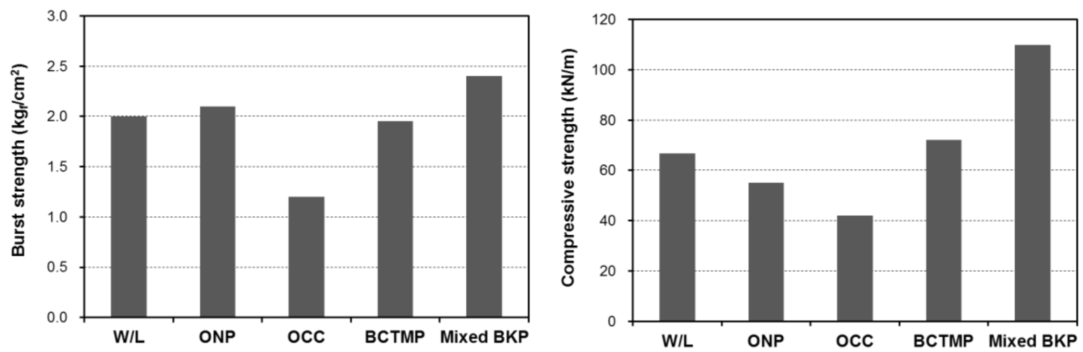

Fig. 6. Burst strength (left) and compressive strength (right) of handsheets made from recycled and virgin pulp (W/L = white ledger)

Evaluation of First-Pass Retention and the Physical Properties of Handsheets Made from White Ledger

Figure 7 shows the first-pass retention of white ledger stock using different dosages and types of C-PAMs. C-PAMs have different molecular weights and charge densities; therefore, the first-pass retention values were products of the varying dosages and types of C-PAMs. The majority of the C-PAMs led to increases in the first-pass retention of the white ledger stock. C-PAM C showed the highest first-pass retention, while B and F displayed the second highest first-pass retention values among the C-PAMs. A, D, and E did not produce noticeable increases in first-pass retention compared with the other C-PAMs. C-PAMs C and F had molecular weights that were similar to the molecular weight of C-PAM A, but their charge densities were higher than that of C-PAM A. Moreover, C-PAM B had the highest charge density among the C-PAMs. Because white ledger contains many fillers and pigments, a C-PAM must have a high charge density to gather anionic fillers and pigments (Gess 1998; Im *et al*. 2015). Charge density is an important property of C-PAMs for the improvement of the first-pass retention of white ledger.

As mentioned previously, the retention aid should improve the paper strength. In the current study, the strength of white ledger was lower than the strength of BKP. In this study, three C-PAMs (B, C, and F) that had the highest first-pass retention were selected for further study. Handsheets from white ledger stock with C-PAMs B, C, and F were evaluated for the ability of these C-PAMs to improve paper strength. Paper strength is affected by ash content (Xu *et al*. 2005; Jung *et al*. 2015). Therefore, the effect of C-PAMs on paper strength was analyzed as a function of ash content. Figures 8 through 10 show the breaking length, burst strength, and compressive strength of the handsheets. B and F were similar in strength because of their ash content. C had the lowest paper strength, though its ash content was similar to the ash content of B and F. Compared with C-PAMs B and F, C-PAM C contained a low charge density, suggesting that charge density was an important factor in first-pass retention and strength. The molecular weight of the C-PAMs was also important. The molecular weight of C-PAM B was lower than that of C-PAM F. Of the six C-PAMs, the molecular weight of C-PAM B was the median value. This result indicated that the C-PAM with the highest charge density should also have a molecular weight that is higher than average in order to improve both first-pass retention and paper strength.

The charge density of a C-PAM, which acts as a retention aid, is more important than its molecular weight for improving the first-pass retention and strength of white ledger sheets. The charge density must be sufficiently high to allow the C-PAM to gather anionic fine particles.

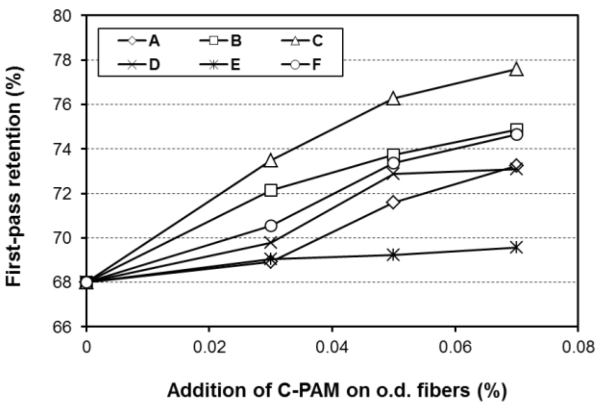

Fig. 7. First-pass retention values of white ledger with different dosages and types of C-PAMs

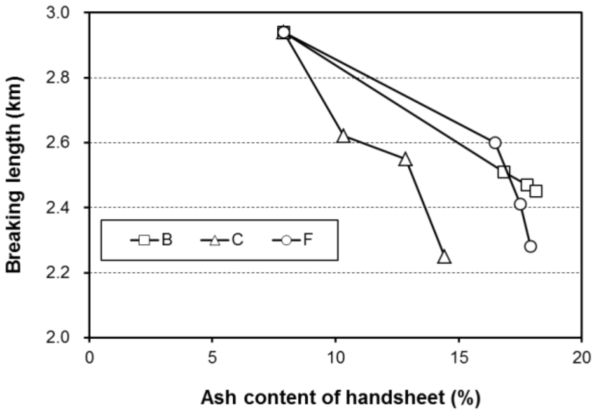

Fig. 8. Breaking length as a function of ash content in handsheets made from white ledger and C-PAMs

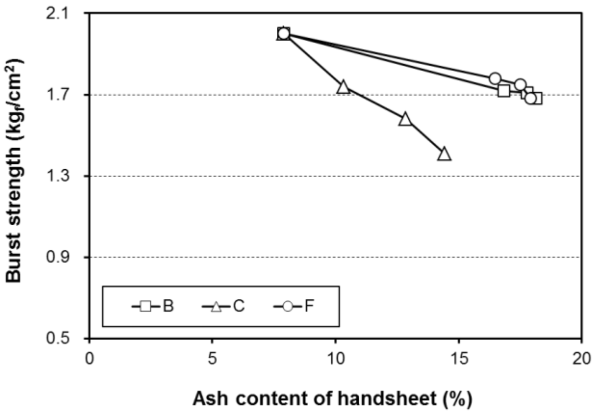

Fig. 9. Burst strength as a function of ash content in handsheets made from white ledger and C-PAMs

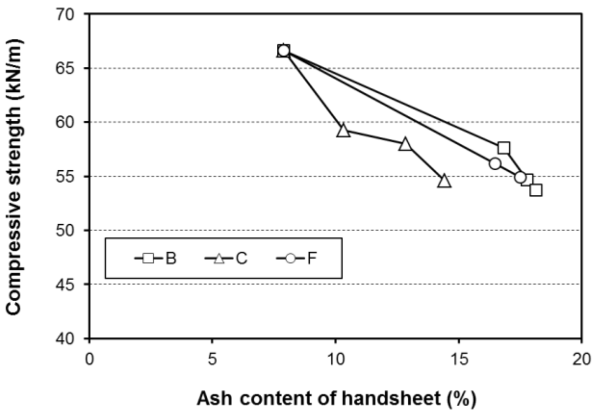

Fig. 10. Compressive strength as a function of ash content in handsheets made from white ledger and C-PAMs

CONCLUSIONS

1. White ledger contained fiber fines and filler fines, which resulted in inferior paper strength compared with the strength of paper made with BKP. Thus, first-pass retention is very important when the amount of white ledger increases in the top ply of a duplex board. Sheet strength must be monitored because an increase in first-pass retention is directly related to an increase in ash content. In addition, a proper additive must be selected.

2. The charge density of a C-PAM, which acts as a retention aid, is more important than its molecular weight in terms of simultaneously improving the first-pass retention and strength of white ledger paper. The charge density must be sufficiently high to allow the C-PAM to catch anionic fine particles.

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