Influence of fines on sheet delamination in Condebelt drying and recyclability of Condebelt-dried linerboard

HAK LAE LEE, TAE MIN JUNG, HYE JUNG YOUN, CHUNG HYUN HAM, AND JIN DOO KIM

ABSTRACT: This study evaluates the effects of the type, content, and distribution of fines on sheet delamination of Condebelt-dried linerboard. As fines content increased, sheet delamination increased substantially. Fibril-like secondary fines caused more delamination in Condebelt drying than did primary fines. Low permeability on the wire side has a determining effect on sheet delamination. In two-ply sheets, the level of delamination increased as the fines content in the bottom ply increased.

We also evaluated the recycling characteristics of Condebelt-dried linerboard. Results showed that the reduction of tensile index after recycling is substantially lower for Condebelt-dried sheets, and the properties of recycled paper depended upon the final drying process used. This report also includes a brief discussion of mill experiences of running the Condebelt dryer and technological improvements at Dong-Il Paper.

Application: This study may allow papermakers to produce better linerboard from recycled furnishes containing significant amounts of fines without sheet delamination problems in Condebelt drying.

The Condebelt drying process, invented by J. Lehtinen, was originally designed to improve drying rates. It has been found to have a wide range of positive effects on sheet properties mainly because it dries the web at elevated pressures and temperatures that are not attainable in conventional cylinder drying [1, 2]. The z-directional pressure and temperature plasticize cellulose and lignin, which promotes fiber flattening, web densification, and interfiber bonding [3, 4]. Furthermore, the Condebelt dryer dries the sheet in a fully constrained condition to improve CD compressive stiffness, which is of critical importance for improving compression strength of corrugated containers [5].

These strength improvement characteristics associated with the Condebelt process are especially beneficial for mills producing linerboard and corrugating medium. Mills can use them to reduce basis weight and increase their use of recycled furnishes or high-yield pulps [6]. Various studies have evaluated the effect of the Condebelt drying process on paper and board properties made from diverse types of pulps and OCC [6-8]. Research shows that Condebelt drying improves many strength properties of linerboard made from repeatedly recycled OCC and that a basis weight reduction of 25% or substitution of 50% of AOCC (American OCC) with KOCC (Korean OCC) would be possible with Condebelt drying [6].

In 1998, Dong-Il Paper Mfg. Co. in Korea installed a 4.5 m wide Condebelt dryer that runs at 650 m/min. Sheet delamination was observed when Dong-Il started drying its two-ply linerboard with the Condebelt dryer. Although the problem of delamination is well documented when drying heavyweight webs by impulse drying [9, 10] no such problems have been reported in the literature for Condebelt drying. The apparent cause is that Condebelt drying extended the dwell time to a few seconds to achieve maximum outgoing solids [11].

Dong-Il Paper's headbox stock contained a substantial amount of fines, a result of using recycled OCC as the principal raw material. We suggested that fines that impede drainage and vapor permeation are the prime cause of sheet delamination. The immediate objectives of this study were to investigate the influence of fines on sheet delamination in Condebelt drying. We also examined the recyclability of Condebelt dried sheets and noted the mill's experiences running the Condebelt dryer.

EXPERIMENTAL

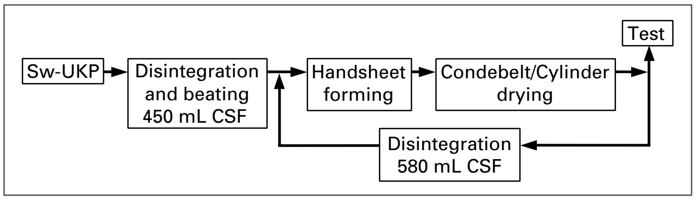
For this study, linerboard produced by Dong-Il Paper from 80% KOCC and 20% AOCC was disintegrated in a high consistency pulper for 30 min, and beaten on a laboratory Valley beater to 290 mL CSF. The long fiber fraction was retained on a 100-mesh screen after beating. To investigate the effect of the types of fines on sheet delamination in Condebelt drying, we collected two different fines and mixed those with the prepared long fibers. We classified one type of fines from the pulp slurry disintegrated in a high consistency pulper for 30 min and heavily beaten to 10 mL CSF on a laboratory Valley beater. We collected fines that passed through a 200-mesh screen but retained on a 400-mesh wire and concentrated those to 10% consistency. These mainly consisted of secondary fines, designated as A type fines (Fines A). The other type of fines, named Fines B in this study, was separated from the disintegrated linerboard slurry using a 200-mesh screen. We used a laboratory sheet mold to prepare handsheets containing 30%, 40%, and 50% of these two types of fines, at a basis weight of 150 g/m^2.

To investigate the effects of fines distribution on sheet delamination, we prepared two-layered handsheets by pressing two wet sheets on a laboratory wet press. Basis weights of the top and bottom plies were 50 g/m^2 and 100 g/m^2, respectively. Fines contents of the top layer varied from 30%-70% at 10% intervals, while fines contents of the bottom ply were adjusted to 20%-50% at 5% interval (**Table I**). In this way, we prepared three handsheets containing an equal amount of total fines, but with differing distribution in the z-direction. Total fines contents varied from 30%-50%.

ONE PLY SHEET:			
Top side	Fines content		
150 g/m²	30%	40%	50%
Wire side			

TWO PLY SHEET:			
Top ply		Fines content	
50 g/m²	30% 40% 50%	40% 50% 60%	50% 60% 70%
Bottom ply		Fines content	
100 g/m²	30% 25% 20%	40% 35% 30%	50% 45% 40%

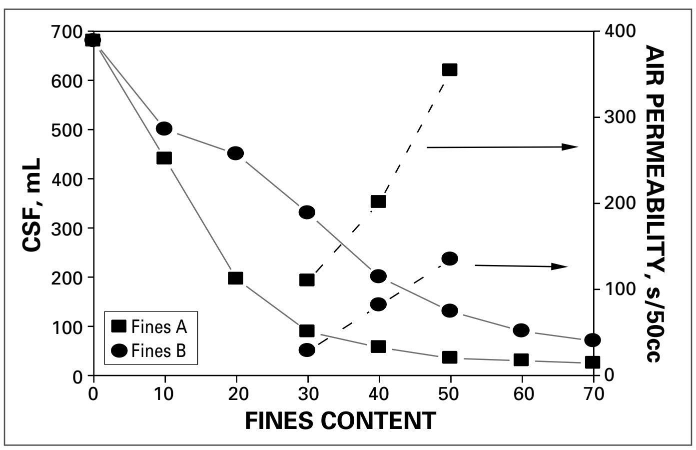
I. The composition of handsheets.



1. Flow diagram for laboratory recycling.

TYPES	PARTICLE SIZE (μm)	WRV (g water/g pulp)	ASH CONTENT (%)
Fines A	38.48	3.81	6.1
Fines B	38.93	1.99	34.0

II. Characteristics of fines used.



2. Effect of the types of fines on CSF and air permeability.

In preparing handsheets containing a given amount of fines, we assumed that long fibers were retained completely in the handsheets. We adjusted the amount of fines added to the long fiber slurry until we obtained handsheets at the target basis weight. For example, to prepare a handsheet at a basis weight of 50 g/m² containing 50% of fines, we prepared long fiber slurry that gives 25 g/m² of grammage. We then added fines until we produced a handsheet with grammage of 50 g/m². We combined two handsheets with the top sides facing and pressed those for 5 min at 3.5 kg/cm². We placed a press felt atop of blotting papers to obtain proper ply bond strength, otherwise, water in the sheet absorbed too rapidly into the blotters.

We used a static rig, designed to simulate the Condebelt process variables including z-pressure, upper and lower platen temperatures, and dwell time, to carry out the laboratory scale Condebelt drying [6]. Upper and lower platen temperatures were 180°C and 80°C, respectively, and pressing pressure was 7 bar. We kept the moisture content of the inlet sheet constant at 40%. We used an image analyzer to determine the delaminated area after Condebelt drying, which was expressed as a percentage to the total area of the sheet. Four measurements were made and averaged for determining the delaminated area.

To investigate the recycling characteristics of Condebelt and cylinder dried papers made from unbleached kraft pulp, we conducted a repeated recycling experiment including disintegration, sheet forming, and drying (**Fig. 1**). In this case, the hot and cold platen temperatures of the Condebelt dryer were 160°C and 80°C, respectively. We used a pressing pressure of 5 bar and pressing time of 5 s. Conventional cylinder drying was carried out at 105°C.

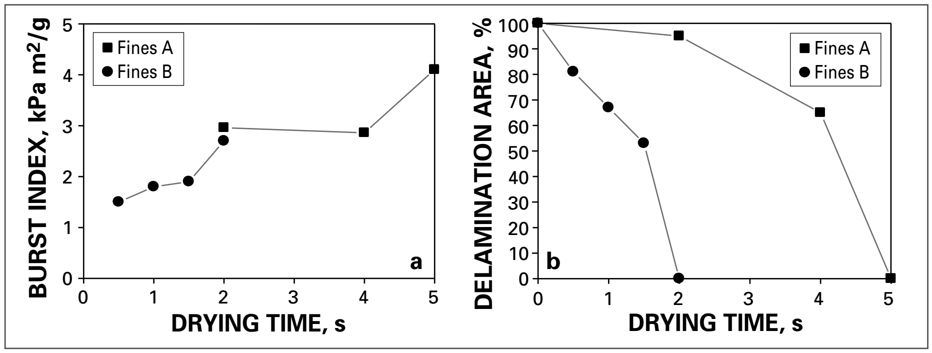
RESULTS AND DISCUSSION

Effect of fines on sheet delamination

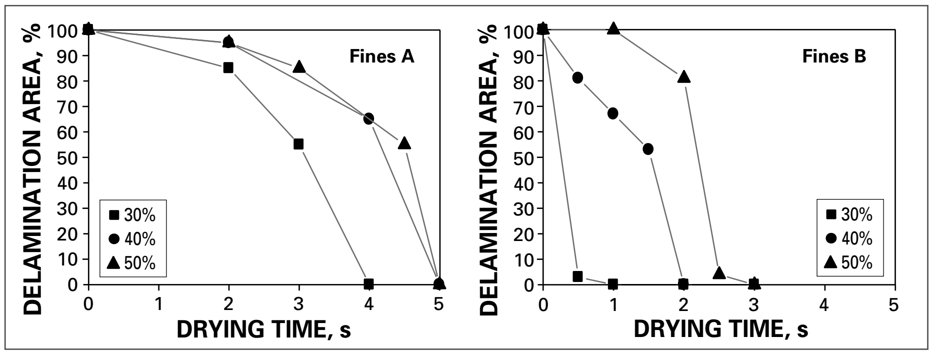
Table II shows the characteristics of the two types of fines used, Fines A and Fines B. We separated Fines A from the heavily refined stock to 10 mL CSF and classified Fines B after simple disintegration of KOCC. Thus, most of Fines A that derived from the beating process were fibrillar in shape, while Fines B contained substantial amounts of ash and fiber debris. Because of the ash, water retention values (WRVs) of Fines A and B were rather low (3.81 and 1.99 g water/g pulp, respectively).

Gurley air permeability for 150 g/m² cylinder-dried handsheets and CSF are depicted as a function of fines content in **Fig. 2**. Fibrillar Fines A decreased both air permeability and freeness more than did Fines B, which consisted of primary fines and dried secondary fines that behave as primary fines. The fact that there existed differences in air permeability and freeness, depending on the type and content of fines, implied that changes in water vapor permeability would occur during drying, causing differences in sheet delamination. Freeness of the wet web is important in Condebelt drying because most of the water is removed in the liquid phase, as opposed to conventional drying where all of the water is evaporated. Air permeability is also critical because water remaining in the sheet after Condebelt drying can flash to vapor during decompression.

To examine the effect of the type of fines on sheet delamination during Condebelt drying, we made Condebelt dried handsheets at a basis weight of 150 g/m² with 40% fines. The area of delamination and burst strength of the sheets are depicted in **Fig. 3**. Handsheets containing Fines B showed less delamination, even though their burst strength was lower than the sheets containing Fines A. This indicates that a reduction in permeability and freeness is more important than the increase of burst strength in sheet delamination. No delamination was observed when the handsheets containing Fines A were dried for 5 s. On the other hand, a drying time of 2 s was enough to avoid sheet delamination in the case of handsheets made from Fines B. We observed substantial delamination for the handsheets containing Fines A and Fines B when drying times were 4 s and 1.5 s, respectively. This suggests that sheets must reach a critical level of dryness to avoid sheet delamination. The burst index also decreased significantly when delamination started to occur. Sheet delamination can be avoided if the internal bond strength of the web is strong enough to resist the vapor pressure in the drying web at the exit of the dryer. Results indicate that improving internal bond strength by refining will not



3. Effect of the type of fines on sheet delamination and burst index.



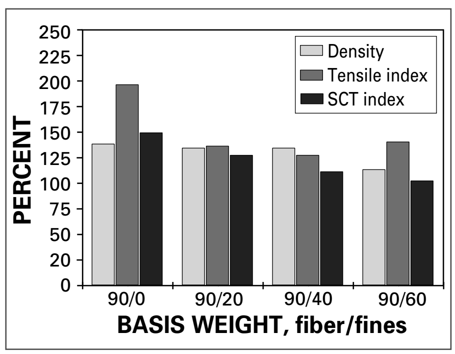
4. Effect of the types of fines and contents on delamination area.

alleviate sheet delamination since sheets refined to higher levels will be less permeable and aggravate delamination.

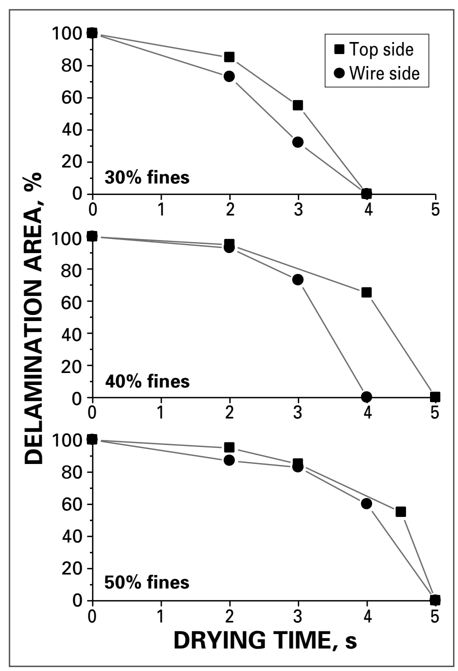
Not only the types of fines, but also the fines content should have an effect on sheet delamination in Condebelt drying. To investigate the effect of fines contents on sheet delamination, we prepared and Condebelt dried handsheets with 30%, 40%, and 50% of fines. **Figure 4** depicts the percentage of sheet delamination. Drying times longer than 5 s were required for the handsheets with 40%-50% of Fines A to prevent sheet delamination, while drying times less than 4 s were enough for the handsheets containing 30% of Fines A to avoid sheet delamination. In the case of Fines B, the drying time at which delamination started to occur was substantially lower. In addition, the effects of fines contents on sheet delamination were more significant. This clearly shows that sheet delamination decreases with the reduction of fines content. The sheet containing high levels of secondary fines is less permeable to flashed steam at the exit of the Condebelt dryer and it tends toward delamination. To produce liners without delamination at high machine speed, therefore, mills should control the level of fines as well as the types of fines to allow easy permeation of water vapor.

We investigated the effect of Condebelt drying on improving sheet strength and density as a function of the amount of fines using handsheets containing a constant amount of long fiber and different amounts of Fines A. Handsheets were either Condebelt dried or cylinder dried and their properties were evaluated. By limiting drying time to 5 s, we avoided sheet delamination in Condebelt drying. Other conditions were the same as depicted in the experimental section. The percentage ratio of the density, tensile strength, and compressive strength of Condebelt-dried sheets to those of conventional cylinder-dried sheets decreased as fines content increased (**Fig. 5**). This indicates that as the amount of fines increases the effect of Condebelt drying on strength improvement diminishes due to less effect on improving fiber bonding by Condebelt drying for flexible fiber fines.

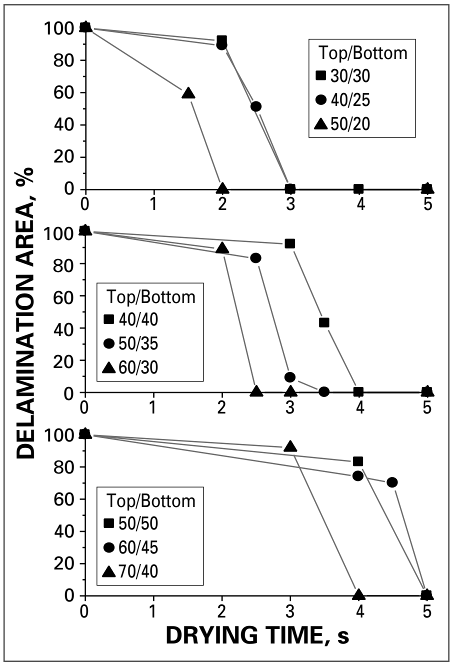
Since Condebelt drying proceeds unidirectionally, variation in z-directional vapor permeability of the web or two-sidedness of fines distribution should play a critical role in sheet delamination. As shown in **Fig. 6**, greater delamination was observed when Condebelt drying was carried out with the top side contacting the hot platen. The fines distribution in z-direction for handsheets is exactly opposite to the fines distribution for machine-made papers due to washing of fines and fillers from the paper surface against the wire. Thus, we see that fines at



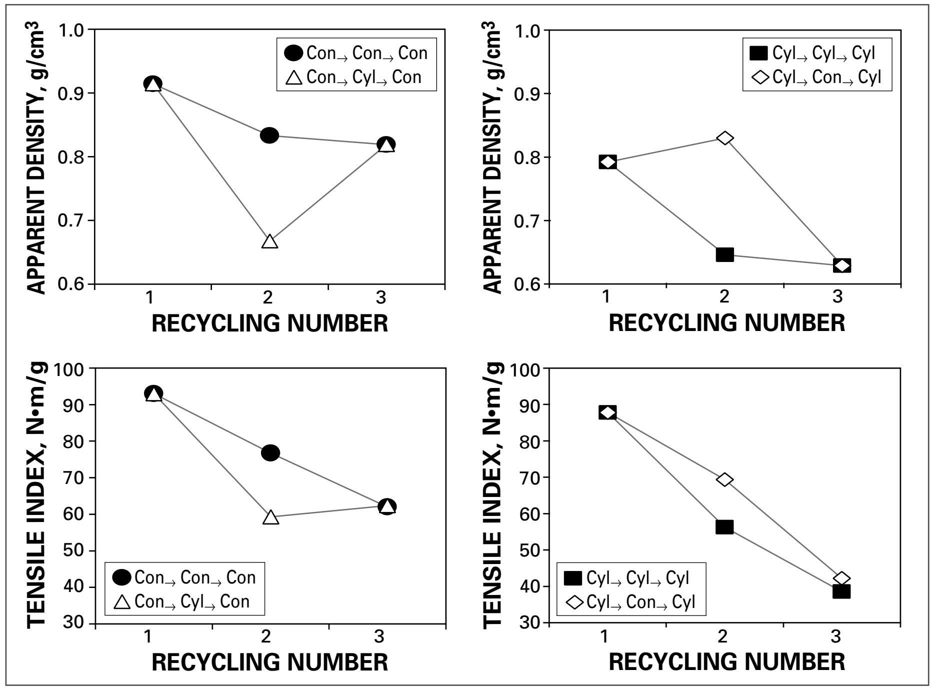
5. Improvement of physical properties by Condebelt drying for sheets with different amounts of fines. The amounts of fines were varied to give 20 to 60 g/m² of basis weight and the long fiber content was kept constant to give 90 g/m² of basis weight. Properties were expressed as percentage of cylinder-dried sheets.



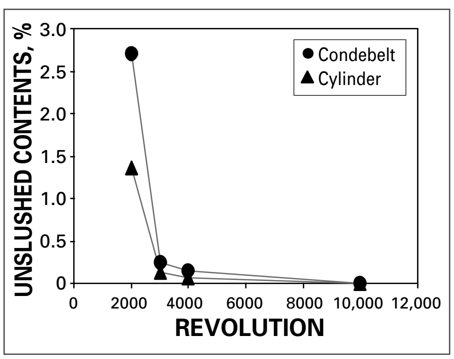
6. Effect of the content of Fines A and two-sidedness of handsheets on sheet delamination area in Condebelt drying. Top side: Condebelt dried with top side contacting the hot platen of Condebelt dryer. Wire side: Condebelt dried with wire side contacting the hot platen of Condebelt dryer.



7. Effects of total fines contents and their distribution in the top and bottom ply on sheet delamination area.



9. Effect of Condebelt and cylinder drying on apparent density and tensile index (Con: Condebelt dried, Cyl: cylinder dried).



8. Disintegration characteristics of Condebelt and cylinder dried liners.

paper surface that contact Condebelt wires impede the permeation of water vapor. In the case of impulse drying, Lindsay used an idealized model to simulate the importance of permeability [12]. Decreased permeability allows higher vapor pressures to be sustained because there is less relief due to gas-phase volume expansion from the motion of the liquid seal. A low-permeability sheet will have a higher vapor pressure in the nip during impulse drying, and the decreased permeability means a reduction in vapor venting once the sheet leaves the nip. As the sheet leaves the nip, the vapor pressure in a low permeability sheet may remain high, with the possibility of delamination if the pressure drop in the escaping vapor across the thickness of the sheet exceeds the z-directional strength of the sheet [13].

Decreasing fines content in the sheet will alleviate delamination problems and foster strength improvement through Condebelt drying. However, removing fines from KOCC is economically unfeasible because it contains more than 30% fines, and the fines content in the headbox often approaches 50%. Fractionating and strategically incorporating the fines in the web structure where fines cause the least impact on sheet delamination may be a solution for the problem associated with using KOCC, which contains substantial amounts of fines. To test this hypothesis, we examined the effects of fines distribution in two-layered sheets on sheet delamination. We kept the total amounts of fines constant, but varied the fines contents in the top and bottom plies (Table I). As shown in **Fig. 7**, sheet delamination decreased as the fines content in the bottom layer decreased.

Recycling characteristics of Condebelt-dried linerboard

The most prominent beneficial effect of Condebelt drying—better strength properties than conventional drying—is due to an increase of the total area of inter-fiber bonding in sheets. The inter-fiber bonds formed by Condebelt drying possess wide, crescent-like corner fillets, and their resistance to the destructive effect of humidity is substantially greater than that of cylinder dried ones [14]. These fillets can resist the effects of water better than the fibrillate-type fiber bonds in conventionally dried sheets [5]. Such findings raised questions about the recycling characteristics of Condebelt-dried papers. The first question was whether the Condebelt-dried sheets would disintegrate as easily as cylinder-dried sheets. If not, how much do they differ in disintegration characteristics? The second question was whether the previous drying conditions would affect the paper properties after repeated recycling.

To evaluate the ease of disintegration for cylinder-dried and Condebelt-dried liners made from 20% AOCC and 80% KOCC, we determined the amount of unslushed fibers using a Sommerville screen with a screen slot size of 0.25 mm. We depicted the results as a function of the revolutions of a standard disintegrator (**Fig. 8**). In the early stage of disintegration, the amount of unslushed fibers was substantially greater for Condebelt-dried sheets than cylinder-dried sheets. The difference decreased, however, as disintegration proceeded and reached complete disintegration for both sheets, suggesting that even though strong inter-fiber bonds formed in Condebelt drying might impede disintegration of fibers in the early stage, there should be no problem in disintegrating the Condebelt-dried linerboards. In practice, Dong-Il Paper never experienced problems associated with unslushed furnishes.

The influence of recycling of Condebelt-dried and conventional cylinder-dried sheets on apparent density and tensile index was investigated following the procedure depicted in Fig. 1 and shown in **Fig. 9**. Results showed that the reduction of tensile index after recycling is substantially lower for Condebelt-dried sheets than for cylinder-dried sheets. It also showed that the properties of recycled liners depended upon the final drying process, irrespective of the previous dying process. The fact that greater strength properties can be preserved after repeated recycling by Condebelt drying indicates that it will be possible to keep the recycling potential of fibers for an extended number of recycling steps.

Practical experiences of Condebelt drying in Dong-Il Paper

Dong-Il Paper completed installation of its Condebelt dryer in May 1999. Running the Condebelt dryer at a speed of 650 m/min, however, was not an easy task. Sheet delamination caused significant loss of production. Knowing that it is critical to place the fines on the top side of the web, the mill decided to modify its stock preparation and forming section processes. For stock preparation, the mill installed flotation cells to effectively separate fines. Since it is not economically feasible to discard the separated fines, they need to be incorporated in the sheet. Because fines separated by flotation cell contains stickies, however, it is not possible to put them on the top or bottom layer of the sheet. When fines are placed in the top layer, substantial deterioration of the appearance results. When placed in the bottom layer, greater sheet delamination results. So, we decided to put the separated fines in the middle ply. To achieve this, the mill rebuilt the paper machine to have three headboxes in place of the original design that used two headboxes. The fines separated from the bottom stock in the flotator are being added to the middle ply stock to keep the sheet more permeable to water vapor. The combination of technologies of fines fractionation by floatation, three-ply forming, and Condebelt drying proved a success for producing quality linerboard from recycled furnish.

CONCLUSIONS

Condebelt drying technology has been used successively to improve strength properties of linerboard made from repeatedly recycled fibers. A problem of delamination limited the operating window for the Condebelt drying process. Since the furnish contained a significant amount of fines, we hypothesized that fines decreased the permeability of the web and caused sheet delamination. To verify this hypothesis, we investigated the effects of the type, content, and distribution of fines on the delamination of Condebelt dried linerboard.

We observed that sheet delamination became more severe as fines content increased. Fibril-like secondary fines caused more delamination in Condebelt drying than did primary fines. Low permeability on the wire side appeared to have a determining effect on sheet delamination. To examine the effect of fines distribution in z-direction on sheet delamination, we prepared and Condebelt dried two-layered handsheets composed of two handsheets containing different amounts of fines. Results showed that as fines content in the bottom layer increased, the level of delamination increased.

We also evaluated the recycling characteristics of Condebelt-dried linerboard. We found that strong inter-fiber bonds formed in Condebelt drying might impede disintegration of fibers in the early stage of disintegration, but there should be no problem in disintegrating the Condebelt dried linerboards. In examining the influence of Condebelt and conventional cylinder drying on recycled paper properties, we found that recycled paper properties depended upon the final drying process employed rather than the type of the drying process used in previous recycling stages. Sheet delamination problems encountered while running the Condebelt dryer at Dong-Il Paper were solved by separating fines in the bottom ply stock by flotation cells and placing them in the middle ply. **TJ**

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INSIGHTS FROM THE AUTHORS

Why did you choose this topic to research?

Dong-Il Paper Mfg. in Korea started running a Condebelt dryer in 1999. Condebelt drying improved many strength properties of linerboards and this allowed Dong-Il either to substitute high quality OCC with less expensive raw materials or to reduce basis weight. Running the Condebelt at high speed, however, caused sheet delamination, which serious hurt product quality. To solve this problem we decided to study the relationship between the type, amounts and z-directional distribution of fines and sheet delamination phenomena in Condebelt drying.

How does this research either compliment and support previous research you (or others) have done? How does it differ from previous research?

In the previous work (Hak Lae Lee, Hye Jung Youn, Tae Min Jung and Jin Doo Kim, Improvement of linerboard properties by Condebelt drying, *TAPPI JOURNAL* 83(7): 74 (2000)) we investigated the effect of the variables of Condebelt drying on linerboard properties. The improvement of sheet properties by Condebelt drying is meaningful only when the products do not show any quality defects like delamination.

What was the most difficult aspect of this research and how did you address that?

Sheet delamination is related to the vapor permeation characteristics of the web, which is associated with the amounts, types and distribution of fines in the sheet. Since the Korean OCC contained substantial amount of fines, it was not economically feasible to fractionate the fines and discard them to solve the delamination problem. This requires us to find the place for the fines in the sheet structure where the sheet appearance as well as vapor permeation are not impaired. Furthermore, it was required to find a method to separate fines efficiently from the whole stock.

What did you personally discover from this research? What was most interesting or surprising about your findings?

Separating fines via flotation and mixing them to the middle ply stock was effective in improving Condebelt drying efficiency thereby solving sheet delamination problems. Condebelt drying does not deteriorate the recycling potential of fibers, and this aspect was a good surprise for us.

How might mills benefit from or use this information?

If any mill wishes to use Condebelt drying for producing linerboards, this information should be very helpful.

What's the next step?

At the moment we are working on methods to conserve the recycling potential of papermaking fibers that include not only Condebelt drying but also fractionation of fibers and mechanical/chemical treatments of the fractionated stocks.

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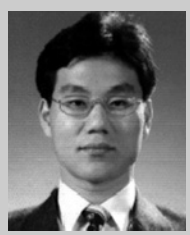

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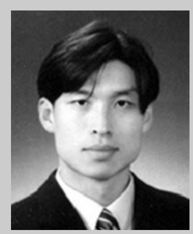

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