Journal of Korea TAPPI
Vol.42. No.5, 2010
Printed in Korea

Improvement of Strain and Elastic Modulus of Linerboard to Prevent Score Crack

Seong Min Chin, Ik Sun Choi, Hak Lae Lee, and Hye Jung Youn†

(Received December 4, 2010: Accepted December 22, 2010)

ABSTRACT

When corrugated board is folded at the severely low humidity condition, crack can occur along the scored (or creased) lines of linerboard. This phenomenon is called as score (or crease) crack. It is mainly resulted from the excessive concentration of stress on the outer layer of linerboard. To overcome score crack, many approaches including the installation of constant temperature and humidity system, displacement of low grade raw material by long and strong fibers, or application of water have been tried. We examined the effect of the weight fraction of top layer in two-ply sheet, freeness of top layer stock and wet pressing on strain and elastic modulus of sheet to prevent score crack. Lower freeness and higher press load increased the density and elastic modulus of sheet. Pressing load over the 50 kg_f/cm^2, however, decreased the strain of sheet. The weight fraction of top layer had positive effect on strain as well as elastic modulus without increasing the density of sheet.

Keywords : *Score(crease) crack, linerboard, strain, elastic modulus, weight fraction, freeness, wet pressing, density*

1. Introduction

Crack is frequently observed on scored or creased line of corrugated fiberboard boxes at the severely low humidity condition. After scoring, crack can happen when board is folded. This phenomenon is called "score or crease crack"(1, 2). Scoring defects are attributed to scoring process such as misalignment and insufficient clearance of male-female scoring heads, damage to scoring anvil or scoring profile. Linerboard problems like low quality materials, bad formation, fiber orientation, etc. are also causes of score crack (3). When a thick linerboard or fiberboard is folded, its outmost layer is subjected to excessive stress. If the outer layer of linerboard is weak or stretched insufficiently because of the above mentioned problems, there could bring about a crack on the scored line.

Score crack has been bothersome to many corrugated board manufacturers, since it is a quality trouble in final stage just before consumer market. It means serious cost loss aspect of material and energy to linerboard, corrugated fiberboard and corrugated

• Department of Forest Sciences, College of Agriculture and Life Sciences, Seoul National University, Seoul 151-921, Korea
† Corresponding Author:E-mail; page94@snu.ac.kr

fiberboard box manufacturers.

To solve this problem, many approaches including the installation of constant temperature and humidity system, displacement of low grade raw material by long and strong fibers, or application of water have been tried (1). Most of these methods have a defect of high cost and modification or replacement of equipment is not fundamental remedy. Therefore it is desirable to improve the properties of paper by upgrade of fiber quality upgrade of fiber quality or proper economical allocation of fiber raw materials.

Emslie and Brennman (4) elucidated the theoretical principle of scoring and insisted that delamination stress should be higher than plybond strength of linerboard to carry out the scoring without crack. Delamination stress is deeply related with elastic modulus of linerboard, score width, depth, etc. Especially, there is a linear relationship between elastic modulus and delamination stress. In addition, Youn *et al*. (5) reported that strain considerably decreased at the low humidity condition. Therefore, the increase of elastic modulus and strain of linerboard would be one of remedies to prevent score crack.

In this study, we intended to examine the effect of the weight fraction of top layer in two-ply linerboard, freeness of top layer stock and wet pressing on strain and elastic modulus of sheet to prevent score crack.

2. Experimental

2.1 Material

Softwood unbleached kraft pulp (Sw-UKP, Russia) was used to make two-ply handsheet.

2.2 Stock preparation

UKP fibers were refined by Valley beater with 3 levels of freeness: 570, 485, 408 mL CSF. To visualize the cross section of sheet and measure the density of each ply, pulp stock for top ply only was stained with blue color dye.

2.3 Two-ply sheet forming

Handsheet was composed of two plies, top and back ply. Basis weight of two-ply sheet was 240 g/m^2. Weight fraction (grammage) of each ply was shown in Table 1. Top ply was formed from stock with different freeness, and freeness of bottom layer stock was kept at 485 mL CSF. Handsheet forming was conducted with laboratory rectangular handsheet former. Couched top layer sheet was combined onto back ply sheet, and then they were coughed together. After couching, two-ply sheet was pressed with different pressure (Table 1). Drying was conducted by using laboratory drum dryer.

2.4 Measurement of mechanical properties

Handsheet was pre-conditioned at 23℃ and 50% RH before testing. Mechanical properties including tensile strength, strain, elastic modulus, compressive strength and burst strength of sheet were measured in accordance with TAPPI test method T410 om-98, T410 om-97, T494 om-96, T822 om-93 and T403 om-97.

2.5 Measurement of density by image analysis

Handsheet formed with stained fibers was cut as size of 15 mm × 1 mm. A specimen was attached to slide glass to observe the cross section of sheet. The cross sectional image was obtained by using optical microscope of 150 magnification. Effective thickness was calculated from dividing polygon area of each ply by horizontal length of image. From this effective

Table 1. Variables of handsheet forming condition

	Top ply	Back ply
Weight fraction, %	12.5	87.5
	20.8	79.2
	29.2	70.8
Freeness, mL CSF	570,485,408	485
Press pressure, kg$_f$/cm^2	10, 30, 50, 70	

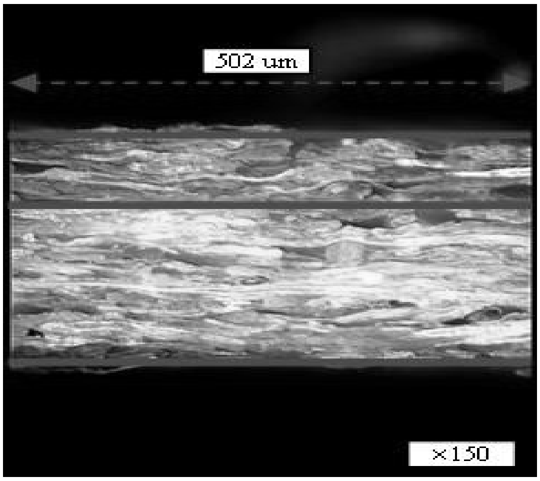

Fig. 1. Cross sectional image of handsheet.

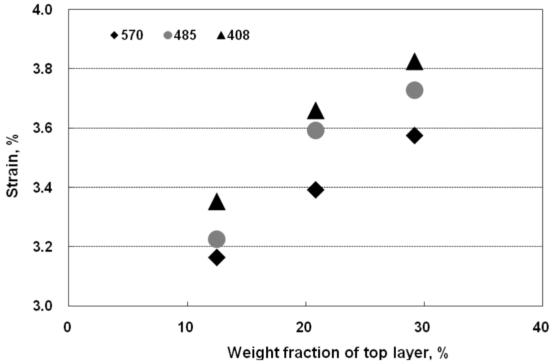

Fig. 2. Strain of two-ply handsheet with weight fraction and freeness of top layer.

thickness and grammage, density of each ply as well as sheet was calculated. Fig. 1 shows an example for calculating the density of top layer from the image of handsheet which was composed of 50 g/m^2 of top layer and 190 g/m^2 of back layer. Polygon area of top layer was 39,178 ㎛^{2} and horizontal length of image was 502 ㎛. Therefore, the average effective thickness of top layer was 78 ㎛, and the density of top layer was 0.641 g/cm^3.

3. Results and Discussion

3.1 Effect of weight fraction and freeness of top layer on strain and elastic modulus

Score crack is a seasonal problem. It happens dominantly in the winter season. Therefore, it is required to improve properties which are weak points in low humidity condition. According to Youn *et al.*'s report (5), tensile, burst and compressive strengths increased but strain was deteriorated when relative humidity was lower than 50% like winter season. We tried to improve strain by controlling fiber freeness and weight fraction of top layer.

Fig. 2 shows the strain of two-ply sheet which is made of top and back ply. As the weight fraction of top layer increased, strain increased linearly. About 15% of increase of strain was observed with increase of weight fraction of top layer from 12.5% to 29.2%. Although top layer stock had the same freeness as back layer, the strain was dependent on weight fraction of top layer. When the grammage of top layer was increased, structural unevenness was reduced and stress was easily propagated so that strain could be increased. It indicates that structural evenness of sheet is good for improving strength. The proper allocation of grammage for each layer has good influence on strain, but it has a limitation of production cost. When the freeness of top layer stock was lowered by refining, the strain of sheet was increased. About 7% of increase of strain was obtained with the decrease of freeness of

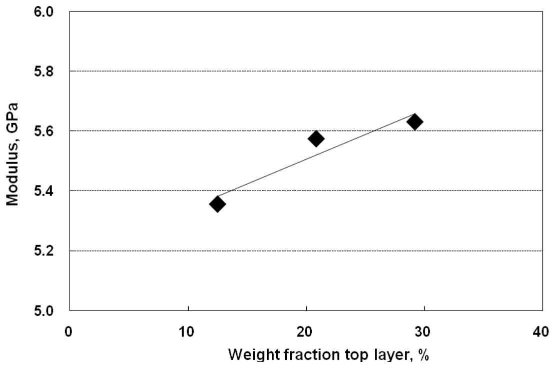

Fig. 3. Elastic modulus of two-ply handsheet with weight fraction of top layer.

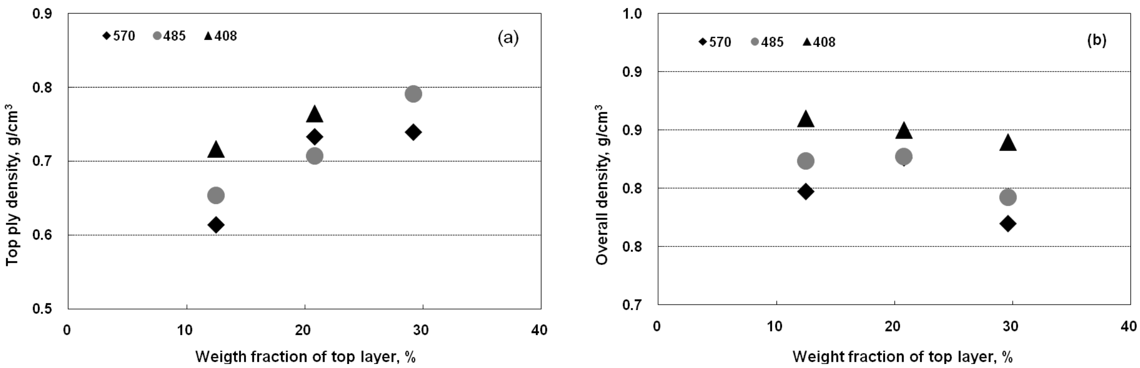

Fig. 4. Top layer density (a) and overall density (b) of two-ply handsheet.

top layer stock from 570 mL CSF to 408 mL CSF. It also contributed to improvement of the strain, but its increase rate was smaller than the case of the top layer weight fraction. In other to say, freeness has a limitation for improving strain continuously.

Elastic modulus is also critical property which affect score crack according to Emslie and Brennman (4). Fig. 3 shows the elastic modulus of two-ply sheet which is made of top with 408 mL CSF freeness and back ply with 485 mL CSF freeness. Similar to the strain, elastic modulus also increased with linear relationship. Higher elastic modulus was obtained with increase of weight fraction of top layer. As the weight fraction of top layer was increased from 12.5% to 29.2%, elastic modulus increased by 5%.

As the basis weight of top layer increased, the density of top layer in two-ply sheet increased (Fig. 4-(a)). Though there is little change of the overall density of two-ply handsheet (Fig. 4-(b)) with change of weight fraction of top layer, it seemed higher density in top layer contributed to improve elastic modulus of sheet. Moreover, lower freeness of top layer led to higher density of two-ply handsheet obviously (Fig. 4).

For two-ply handsheet with the top ply weight fraction of 12.5%, elastic modulus increased about 3% with the decrease of freeness of top layer stock from 570 mL CSF to 408 mL CSF (Fig. 5). Refining generates fibril and fines so that relative bonded area, density and mechanical strength increase. Similar trend was observed for other weight fractions of top layer.

3.2 Effect of wet pressing on strain and elastic modulus

Wet pressing is a representative unit process to increase paper density. Densification by wet pressing is much higher than one by refining. In this experiment, density increased remarkably with the increase of press pressure up to 50 kg_f/cm^2. Generally, higher density improves the strength of sheet because of increase of relative bonded area between fibers. Elastic modulus of two-ply sheet was greatly improved by wet pressing. As shown in Fig. 6-(a), about 30% of elastic modulus was improved when pressure was increased from 10 kg_f/cm^2 to 50kg_f/cm^2.

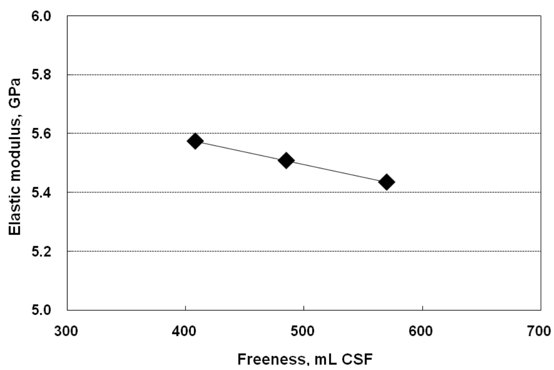

Fig. 5. Elastic modulus of two-ply handsheet with freeness of top layer stock.

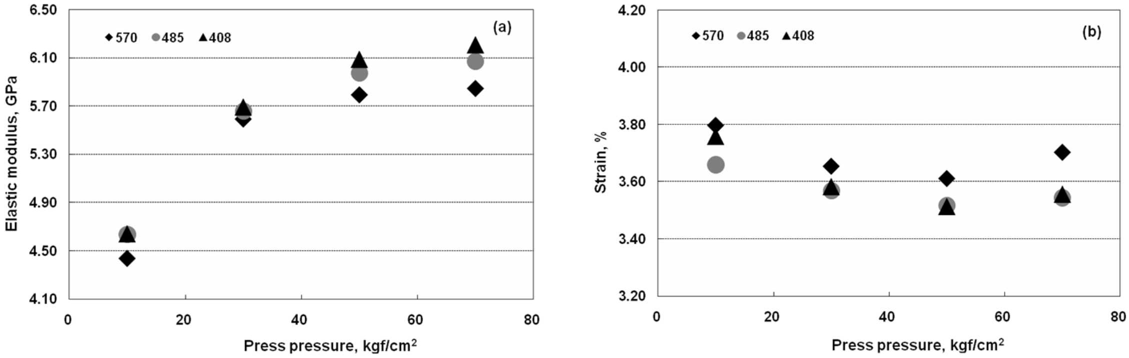

Fig. 6. Elastic modulus (a) and strain (b) of two-ply handsheet with wet pressing pressure.

Above 50 kg_f/cm^2 of press pressure, the elastic modulus was insignificantly changed because of little increase of density. Fig. 6-(b) shows the strain with wet pressing load. Contrary to elastic modulus, the strain of two-ply sheet decreased slightly with the increase of press load. It means that densification by wet pressing made the sheet brittle. Consequently, wet pressing is not suitable to improve the strain. To prevent score crack, it is needed to improve the elastic modulus without deteriorating strain.

3.3 Effect of density on elastic modulus and strain

Fig. 7 describes the effect of the weight fraction and freeness of top layer and wet pressing on elastic modulus and strain of two-ply sheet. Higher weight fraction of top layer, higher effective elastic modulus. When the weight fraction of top layer (solid line) increased from 12.5% to 29.2%, about 5% of increase of elastic modulus was observed. Increased density of top layer by refining (dash line) improved the elastic modulus. Wet pressing (two point line) up to 50 kg_f/cm^2 contributed to the increase of elastic modulus by 30%. Wet pressing made the sheet much denser. On the other hand, strain was improved by refining treatment and the increase of weight fraction of top layer, but wet pressing treatment decreased the strain despite of higher densification. Refining led to increase of strain as well as density. It is noteworthy that control of weight fraction of top layer enabled the sheet to have high elastic modulus and strain without increase of density. In the case of three-layer linerboard with a limitation of increasing top layer weight fraction, it can be suggested to control freeness

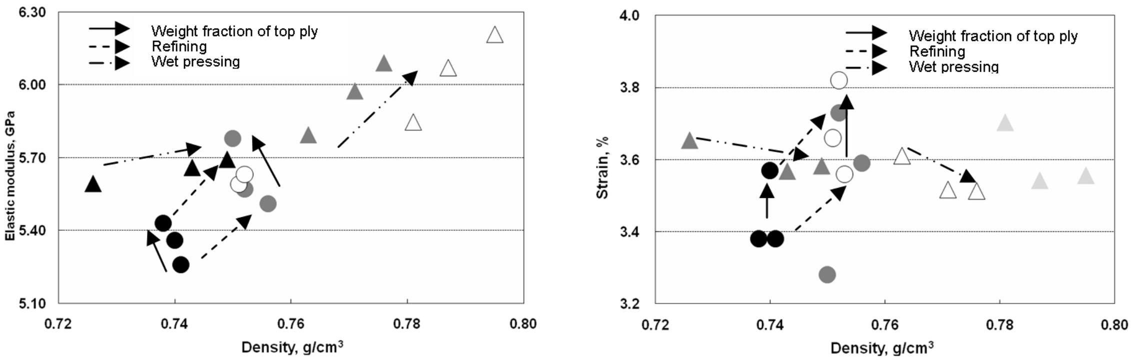

Fig. 7. Elastic modulus (left) and strain (right) with the density of two-ply sheet.

of the middle layer stock while keeping top layer weight fraction as high as possible.

4. Conclusions

To prevent score crack which is a major quality problem of corrugated fiberboard box in winter season, several factor including the weight fraction and freeness of top ply and wet pressing load were investigated in this study. Lower freeness and higher press load increased the density and elastic modulus of sheet. high pressing load, however, decreased the strain of sheet. The weight fraction of top layer had positive effect on strain as well as elastic modulus without increasing the density of sheet. It could be considered as a good solution for alleviating score crack of corrugated fiberboard.

Acknowledgement

This work was supported by Ministry of Commerce, Industry and Energy and partially by Brain Korea 21 Project, Korea Research Foundation.

Literature Cited

1. Kim, S.C., Corrugated board technology, Yejin, pp.156-163 (1997).
2. Savolainen, A., Papermaking Science and Technology, vol.12, TAPPI Press, pp.228-235 (1998).
3. Corrugating Defect/Remedy Manual, 6^{th} ed., TAPPI Press, pp.176-177 (1999).
4. Emslie, A.G. and Brennman, R.S., Theoretical and experimental study of the scoring and bending of boxboard, Tappi Journal 57(6):289-297 (1967).
5. Youn, H.J., Lee, H.L., Chin, S.M., Choi, I.S., Physical properties of linerboard and corrugated fiberboard at the cyclic condition of low humidity, Journal of Korea Technical Association of the Pulp and Paper Industry 39(2):38-44 (2007).