Journal of Korea TAPPI
Vol.38.No.5, 2006
Printed in Korea

Effect of Roughness and Densification of Precalendered Sheet on Surface Roughening

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

(Received May 22, 2006: Accepted October 29, 2006)

ABSTRACT

To meet the ever increasing quality demand of coated papers and duplex boards, the local gloss variation and print unevenness must be avoid. To do this, surface roughening phenomenon which affects local gloss and print unevenness was investigated. In this study, the effect of roughness and densification of sheet obtained at various calendering conditions on surface roughening was examined. To evaluate the calendering effect properly we introduced a new value of roughening index by moisture for evaluation of surface roughening.

Caliper and roughness of sheet decreased with increasing of calendering temperature and pressure, and the remarkable reduction of those properties occurred at the temperature around Tg. Roughening index increased when the amount of water increased and calendaring temperature and pressure increased. And as the sheet became denser by calendering, the roughening index increased to some extent. But roughening index by moisture is the lowest for sheet precalendered at higher temperature condition. When the surface of calendered sheet is rougher, there is more roughening of surface. The severe condition of calendering made the roughening index by moisture small.

Keywords *: precalendering, surface roughening, density, roughness, roughening index by moisture*

1. Introduction

To meet the ever increasing quality demand of coated papers and duplex boards, the local gloss variation and print unevenness of these products must be avoided. Local gloss variation is one of the most important qualities to lower preference to products and print unevenness is primarily induced by density variation of the sheet. These quality problems are caused by many factors including poor formation and surface roughening of sheet during coating or printing. Surface

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

roughening is the phenomenon that the fibrous network of the paper is permanently deformed with absorption of water (1). It is affected by 1) the affinity to water of paper sheet which is dependent on pulp type, 2) condition of coating and printing, for example, the amount of water, water retention value of coating color, contact time and so on, and 3) the ability to recover the original shape and relax the stress in drying and calendering process (2). According to the study by Skowronski et al, roughening phenomenon would be due to the internal stresses in the cell wall tending to restore the structure of its original form and fiber shape recovery process predominates in mechanical pulp fibers compared to chemical pulp (3). It was evaluated using a technique to measure the swelling pressure exerted when paper is contacted by water. The more water is applied on paper and the contact time between water and base paper is longer, the greater is the surface roughening of base paper (4). Water retention value of coating color also affected on roughening. Decreased absorption of water by hydrophobic sizing and beating has little influence on roughness of coated paper (5).

Calendering is a process that can change the bulk, caliper, and roughness of base sheet depending on calender type and operating condition. It is kwon that precalendering improves the gloss and print density and reduces the roughness of the coated woodfree paper. Type of calender and calendering variables affect mass distribution of the coating layer negatively or positively (6, 7). Generally, precalendering has positive effects on properties and the uniformity of coated products, but induced stress in the sheet by precalendering and the ability to release this stress would be various depending on the type of calender and condition. For instance, TG calendered sheet shows less roughening than conventional one (2).

Precalendering must be one of critical factors in surface roughening, but its effect has not been investigated completely. Surface roughening was mostly evaluated by measuring the change of PPS roughness and gloss after water application (2, 8). Also, image analysis of paper surface under low angle double beam illumination and analysis of scanning electro microscope stereo images were used in previous researches (9, 10). Most of measurements are carried out on the surface contacted with water and they can evaluate the roughening of precalendered sheet by water absorption. As these methods do not consider the deformation of sheet occurred in precalendering, however, the relationship between surface and structural properties of precalendered sheets and surface roughening by moistening seems to be obscure. In this study, therefore, the effect of precalendering on surface roughening phenomenon was investigated as a function of roughness and densification of sheet. To evaluate roughening, we used a new index which can consider both deformations caused by calendering and water absorption.

2. Experimental

2.1 Materials

Base paper used in this experiment was a woodfree paper with a fiber furnish of 100% bleached hardwood kraft pulp. The basis weight of the paper was 109 g/m^2. The caliper and PPS roughness of uncalendered sheet were 136 μm and 4.5 μm.

2.2 Methods

2.2.1 Precalendering of base paper

To obtain the sheets with different roughness and density, base papers preconditioned at 23°C and 50% RH were precalendered using a laboratory SNC (Soft nip calender). The moisture content of sheet was 7.9%. Calendering was carried out at the various conditions of roll temperature and linear nip pressure. Temperature was 40, 70, 100 to 120 °C and linear load 114 and 184 kg/cm. Top side of the sheet was faced with the heating roll and the sheet was passed once through the nip.

2.2.2 Measurement of properties

Caliper and roughness of sheets which were uncalendered or calendered were measured at the condition of constant temperature and relative humidity according to TAPPI test method. Roughness was measured using PPS roughness tester (Parker Print-Surf., L&W Co.) and Stylus profiler XP-2 (AmBios tech.). Clamping pressure during PPS test was 2 MPa. Raw data for surface profile with scanning length of 20 mm were obtained from Stylus profilometer, processed through filtering, and expressed as an average roughness value of Ra.

2.2.3 Water application

To evaluate surface roughening by contact of water, we applied water onto the surface of the sheet. We used distilled water. Application of water was done with newly developed apparatus of 3-roll applicator to control the amount of water more accurately and apply water uniformly. Water applicator consisted of three rolls which have hydrophilic surface and the gap between rolls can be adjusted easily. Water was transferred from water pond to the lowest roll and then retransferred from it to top surface of the preweighed sheet injected into the nip between upper two rolls. The amount of water can be controlled by roll speed and the gap between rolls and it ranged from 2 to 16 g/m^2. After application of water paper sheets were air-dried and preconditioned at 23°C and 50% RH.

2.2.4 Evaluation of surface roughening

We measured the caliper and roughness of sheets before and after water application and evaluated roughening by the change of values of the properties. Roughening index is defined by the percentage ratio of the change of value to the initial one before water application. This index is often used by many researchers, but it doesn't consider the calendaring effect, in other words, surface deformation by precalendering and recoverability. When water is applied, a part of sheet deformation caused by precalendering can be recovered and its magnitude is dependent on calendering condition and type of furnish. Therefore, we introduced a new roughening value of roughening index by moisture (RIM) for evaluation of surface roughening. It was expressed by the percentage ratio of a roughness recovery after moistening to the change of roughness by precalendering as shown Eq. [1].

$$RIM\ (\%) = \frac{R_{c,am} - R_{c,bm}}{R_{uc,bm} - R_{c,bm}} \times 100 \qquad [1]$$

where, $R_{uc,bm}$ is a roughness value of uncalendered sheet before moistening, $R_{uc,bm}$ is a roughness value of calendered sheet before moistening, and $R_{c,am}$ is a roughness value of calendered sheet after moistening. It includes roughening by water as well as deformation by calendering.

3. Results and Discussion

3.1 Physical properties of calendered sheet

The caliper and roughness of sheet were

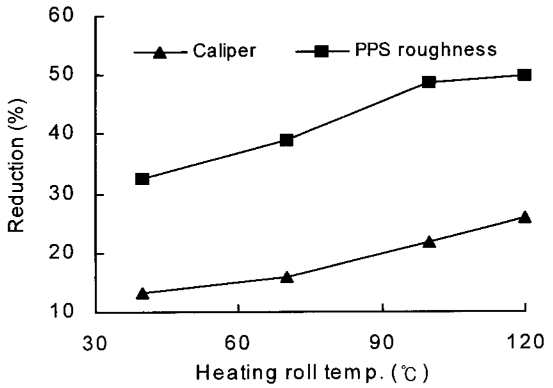


Fig. 1. The reduction in caliper and PPS roughness of sheets by precalendering.

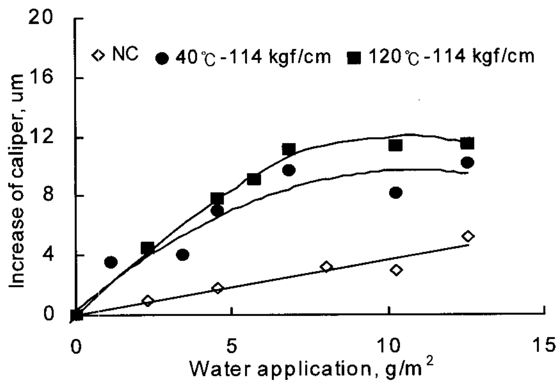


Fig. 2. Increase of caliper of uncalendered and calendered sheets after water application.

decreased by calendering. In this experimental condition, the caliper ranged from 108 to 122 um and roughness ranged from 2.5 to 4.0 μm. The reduction of caliper and PPS roughness by calendering was shown in Fig. 1. The reduction of caliper and PPS roughness increased when the temperature of heating roll increased. Especially, the remarkable reduction occurred between 70 and 100°C. It is due to more softening of fibers at around this temperature. According to Vreeland's work, when the moisture of a sheet is 7.9%, dynamic glass transition temperature of cellulose fiber is about 83.5°C (11). Above this temperature, fibers became softer and more flexible and then can be easily deformed.

3.2 Effect of precalendering on surface roughening

After water was applied onto paper, fibers were swollen by absorption of water and caliper of paper increased. Fig. 2 shows the increase of caliper of sheet after water application. The caliper increases as the amount of applied water increases and remains rather constant above 7 g/m^2. The increase of caliper for uncalendered sheet was the lowest and when calendering was done at severer condition, caliper increased more. Because the initial calipers of sheets uncalendered and calendered at the condition of 40°C and 120°C were 136, 119, and 109 um respectively, the relative increment of caliper is much greater for sheet calendered at higher temperature.

Roughening index of PPS roughness for sheets calendered at the different conditions is shown in Fig. 3. The more water is applied, the more roughening occurs. At the same temperature condition, there is more roughening with increasing of the linear load of calender. The roughness of sheet was reduced more by calendering at higher pressure, but the surface became rather rougher by water

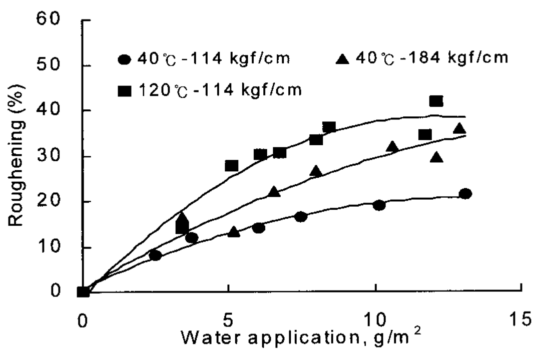


Fig. 3. The roughening index of sheets calendered at the different conditions.

application. The similar result was obtained at the condition of higher roll temperature. In Fig. 3, roughening index for sheet calendered at higher temperature is the greatest in this investigation. As the roughening index is a relative value to the final roughness of a calendered sheet, it can be overestimated when the roughness after calendering became smaller. The roughness of sheet precalendered at the temperature of 120°C was the smallest in this experiment.

Fig. 4 shows the roughening index as a function of density of precalendered sheet. The density of sheet was changed by calendering pressure condition. The sheets with higher density showed more roughening and it is because the compressed fibers and voids by pressure tended to swell with water absorption. But when the sheet was very dense, the tendency of roughening was rather reduced.

Roughening index represents the relative change of properties well, but does not show how much the deformation by calendering is recovered by water absorption. The roughening index by moisture, therefore, is used in this study. From this value, we can know the relationship between changes by calendering and wetting and the magnitude of irreversible deformation of sheet by calendering. Fig. 5 compares the roughening index (Fig. 5-a) and the roughening index by moisture (Fig. 5-b) of Ra obtained from Stylus profilometer. In Fig. 5-a, sheet precalen- dered at the condition of 120°C showed a greater roughening than one of 40°C. But, the final roughness of sheet after water application is smaller. Because roughening index is a relative value to the final roughness of sheet, it is possible to be overestimated if a calendered sheet is smoother. On the other hand, the roughening indices by moisture for two conditions show similar values (Fig. 5-b). That is to say, at both

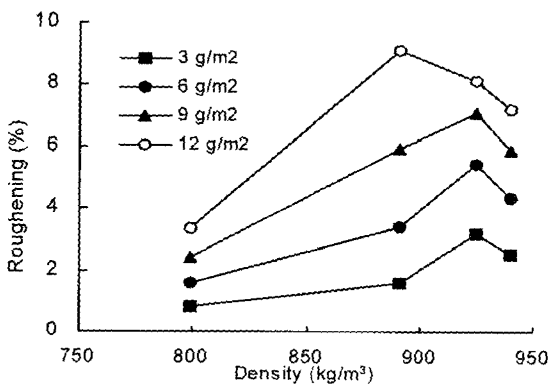
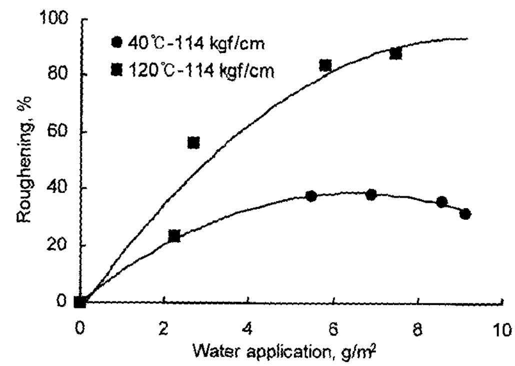
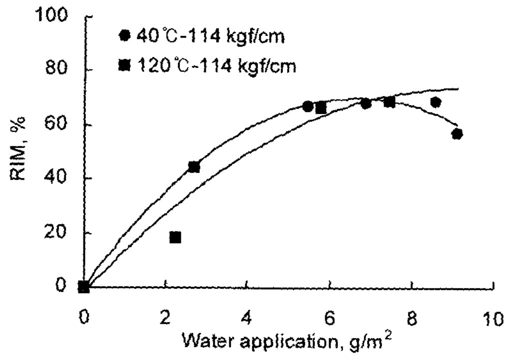


Fig. 4. The roughening index as a function of sheet density.



(a)



(b)

Fig. 5. The roughening index (a) and roughening index by moisture (b) of precalendered sheet.

two conditions, the recovery with similar magnitude on the deformation by calendering happens in application of water even though the values of final roughness are different. For example, when the water of around 6 g/m^2 is applied, the surface of paper regains roughness equivalent to about 65% of that improved by calendering. If RIM is 100%, it means that the roughness of sheet returns to the level of initial roughness of uncalendered sheet.

Fig. 6 shows the roughening index by moisture of PPS roughness for precalendered sheets at the different conditions. These results differ from those shown in Fig. 3. Sheet calendered at the high temperature showed the lowest RIM. It suggested that the re-deformation by the applied water was the smallest and the permanent deformation by precalendering remained in the sheet. According to Skowronski's work, temperature gradient calendering caused a permanent change of surface property and showed less roughening (2). In case of condition of 40°C and 184 kgf/cm, the smoothening effect by calendering would be almost lost when the water of 13 g/m^2 was applied. It suggested that even though the sheet with same level of PPS roughness can

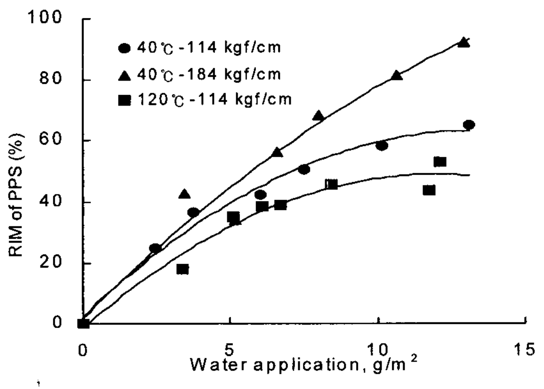


Fig. 6. RIM of PPS roughness for sheet precalendered at the different conditions.

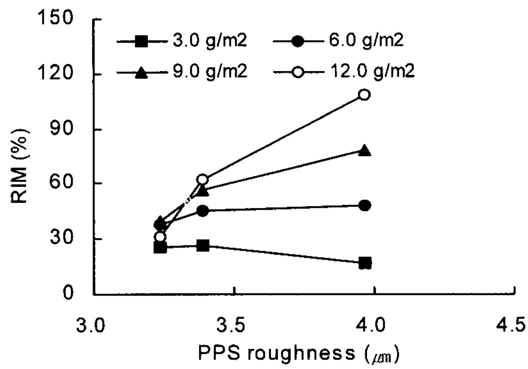


Fig. 7. RIM as a function of PPS roughness of precalendered sheet.

obtain by calendering at the different condition of temperature and pressure, the reaction to absorption of water is different.

Fig. 7 shows the relationship between PPS roughness of calendered sheet and moistened roughening index. The surface roughening becomes greater in general as the sheet roughness increased. Therefore, it is possible to reduce the roughening during coating or printing by precalendering of sheet to some extent (7).

4. Conclusions

The effect of roughness and densification of sheet obtained at various calendering conditions on surface roughening phenomenon was investigated. To evaluate the calendering effect properly we introduced a new index for roughening. New roughening index by moisture represented the extent of recovering roughness by water application to the one decreased by precalendering.

Caliper and roughness of sheet decreased with increasing temperature and pressure of calender, and especially at the temperature around Tg the remarkable reduction of those properties occurred. Roughening index which is a ratio of the change of the value by water absorption to the initial one before water application increased when the amount of water increased and temperature and pressure during calendering increased. And as the sheet became denser by calendering, the roughening index increased to some extent. But roughening index by moisture is the lowest for sheet precalendered at higher temperature condition. When the surface of calendered sheet is rougher, there is more roughening of surface. It suggested that the roughening phenomenon is affected by the irreversible deformation of fibers by water. And it can be controlled by precalendering condition to some extent.

Acknowledgement

This work was supported by grant No. R04-2002-000-20133-0 from Korea Science & Engineering Foundation. It was partially supported by Brain Korea 21 project, Korea Science and Engineering Foundation.

Literature Cited

1. Aspler, J. S. and Béland, M. C., A Review of fibre rising and surface roughening effects in paper, JPPS 20(1):J27-J32 (1994).
2. Skowronski, J., Surface roughening of pre calendered basesheets during coating, JPPS 16(3):J102-J110 (1990).
3. Skowronski, J., Lepoutre, P. and Bichard, W., Measuring the swelling pressure of paper, Tappi J. 71(7):125-129 (1988).
4. Ginman, R., and Visti, J., The drop of gloss of coated web offset paper on printing, Advanced Printing Science and Technology, 11:217 (1973).
5. Pylkkö, J. Mechanical base paper, Pigment Coating and Surface Sizing of Paper, Lehtinen, E. (Ed.), Fapet Oy, Finland, pp.34-36 (2000).
6. Venkata Chinnaswamy, H., Aravamuthan, R., and Scheller, B., Effect of precalendering on surface and printing properties of coated sheets, Proc. 1998 Coating conference.
7. Steffner, O., Nylund, T., and Rigdahl, M., Influence of precalendering on the properties of a coated woodfree paper and the covering ability of the coating, Proc. 1995 Coating conference, pp. 335-343.
8. MacGregor, M. A., Measuring water induced roughening of LWC paper and its effect on printed gloss, Proc. 1996 Process & product quality conference, pp. 129-137.
9. Béland, M. - C., Nguyen, N., De Silveira, G., and Lepoutre, P., A new image analysis method for fibre rising measurement, Proc. 1992 International printing & graphic arts conference, pp. 179-185.
10. Reme, P. A. and Kure, K. - A., Stereo images as a tool to study paper surface topography, JPPS 29(3):86-89 (2003).
11. Vreeland, J. H., Ellis, E. R., and Jewett, K. B., Substrata thermal molding (1), Tappi J. 72(11): 139-145 (1989).