A Study on Unevenness of Paper Surface Properties

-Effect of Hot Calendering on Surface Roughening-

Seong Min Chin†, Hye Jung Youn*, Hyun Do Jung†, and Ik Sun Choi†

*Assistant professor, †Graduated student
Seoul Nat'l Univ., San 56-1, Sillim-Dong, Gwanak-Gu, Seoul, 151-921, Korea
* page94@snu.ac.kr

ABSTRACT

Surface roughening which is occurred by interaction between base paper and water in coating color deteriorates surface properties of coated paper. In this study, the effect of calendering variables on surface roughening and the relationship between hot calendering and water penetration depth were investigated. BCTMP handsheets were calendered at the various conditions of temperature and linear load, and its PPS roughness was measured before and after moistening to evaluate surface roughening. To determine water penetration depth, thickness was measured from the cross sectional images of sheet which were obtained using CLSM technique. High pressure calendering was beneficial to reduce surface roughness before coating but its smoothening effect was mostly lost by contact with water. On the contrary, sheet calendered at the highest temperature showed the lowest roughening. High temperature calendering allowed the smallest penetration of water into fiber network because of sufficient deformation and densification in top side of z-direction of sheet. Consequently, hot calendering could be the effective way to reduce surface roughening and unevenness of paper surface.

INTRODUCTION

As the demand for high quality is ever increasing, unevenness of paper becomes of great importance. Unevenness of paper can be generally reduced by coating which makes paper glossy, bright and smooth. Non-uniformity, however, would be occurred by the interaction between coating color and base paper. During application and metering coating color, water in coating color is absorbed by fibers or in pores between fibers through pressure and capillary penetration. According to previous works, water absorption increases as dwell time from application to metering is long and applied pressure is high (1). This absorption causes weakening of fiber-fiber bonding, release of stress built in drying, and fiber swelling (2). Finally, it makes paper surface rough and uneven. This phenomenon is called by surface roughening. Surface roughening is considered as the permanent distortion and deformation of paper by contact with water or heat (3). It is affected by properties of base paper and operating variables in coating. Many studies have been carried out to investigate its causes and effects and to reduce it. Paper made of TMP shows more roughening than kraft pulp and in case of LWC smoothing effect by precalendering was lost during coating (4). Skowronski et al (5) measured swelling pressure of paper by water and reported that calendered TMP sheet developed a high swelling pressure unlike uncalendered sheet. They concluded that it may be due to the tendency of fibers to recover original shape. According to Engström's research, precalendered LWC showed a greater roughening by contact with water in coating and it affected the distribution of coating mass and print mottle (6). Precalendering improves surface properties of paper but can also deteriorate them in some cases. Its effect on surface roughening is dependent on pulp type, the amount of absorbed water, and calendar variables, i.e., pressure and temperature. Therefore, this study aimed to evaluate the effect of calendaring pressure and temperature on surface roughening. And the penetration depth of water into paper was examined to understand surface roughening in a viewpoint of structural change by hot calendaring and water penetration.

EXPERIMENTAL

Raw material

BCTMP was used for making handsheet. BCTMP was beaten to 470±10 mL CSF using a Valley beater.

Preparation of handsheet

Handsheets with basis weight of 100 gsm were prepared and preconditioned at 23°C and RH of 50%. The moisture content of sheet was 8%.

Calendering

Handsheet was calendered using a laboratory soft nip calendar (SNP). Calendering was carried out at the various conditions of temperature and nip pressure. Temperature was 40, 120, 160°C and linear load 114 and 118 kg/cm.

Water application

Distilled water was applied onto sheet using 3-roll applicator (Fig. 1). The amount of applied water could be controlled by roll speed and the gap between upper two rolls and it ranged from 0 to 30 gsm. After application of water, paper sheets were air-dried and conditioned at 23°C and RH of 50%.

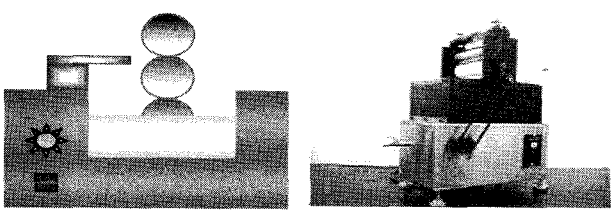

Fig. 1. Apparatus for water application.

Evaluation of roughness

To evaluate the effect of precalendering, roughness of sheets before and after calendaring was measured using PPS roughness tester (Parker Print-Surf, L&W Co.).
And by measuring roughness before and after water application, surface roughening could be evaluated. Surface roughening was expressed as a RIM (Roughening Index by Moisture) in Eq. [1]. It was the percentage ratio of a roughness recovery after moistening to the change of roughness by calendaring.

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

where, $R_{uc,bm}$ is a roughness value of uncalendered sheet before moistening, $R_{c,bm}$ is a roughness value of calendered sheet before moistening, and $R_{c,am}$ is a roughness value of calendered sheet after moistening.

Evaluation of water penetration

When paper is exposed to water, water penetration into pores and fiber swelling occurs simultaneously. We tried to evaluate the penetration depth and fiber deformation by water. Distilled water with fluorescent dye, acridine orange was applied onto paper surface and the cross-section of paper was examined using Confocal Laser Scanning Microscope. Thickness and its change were measured from CLSM images which were processed by image analysis program. The penetration depth was determined by Eq. [2] and image process procedure is depicted in Fig. 2.

$$L = Ti - (Tw - Ts) \qquad [2]$$

where, L is water penetration depth, Ti is initial thickness of sheet before water application, Tw is thickness after water application, and Ts is stained thickness by fluorescent dye.

Fig. 2. Processing of CLSM images.

RESULTS AND DISCUSSION

Effect of precalendering on surface roughening

Fig. 3 shows surface roughening of sheets which were calendered at the different linear pressure. When the amount of applied water increased, the surface of sheet became rougher and rougher. Especially, calendaring with high pressure gave much greater surface roughening to sheet. High pressure calendaring was beneficial to smoothness of a paper, but its effect disappeared by contact with water.

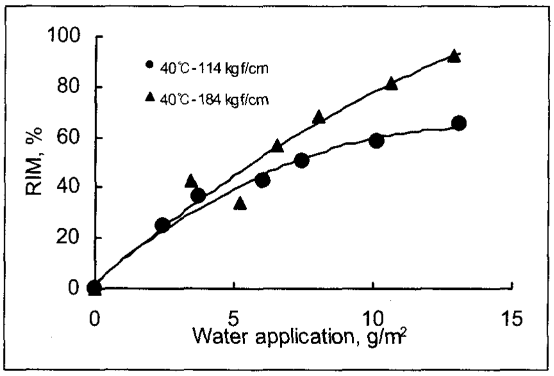

Fig. 3. Effect of linear pressure of calendar on surface roughening.

Surface roughening of paper is affected by calendaring temperature. Fig. 4 shows effect of calendar temperature on surface roughening of BCTMP sheets. Calendering pressure was kept at 114 kg_f/cm. As can be seen, sheet calendered at the high temperature had the lowest RIM. Temperature had a greater influence on surface roughening as the amount of water increased. Contrary to effect of pressure, it can be suggested that a permanent deformation by heat is developed in a paper so it can remain after exposing to water. This result is similar to

Hw-kraft handsheet (7), but its tendency of surface roughening is remarkable in BCTMP sheet. Consequently, deformation and smoothening of BCTMP sheet by pressure can be lost by water, but hot calendaring is effective to reduce surface roughening by permanent deformation.

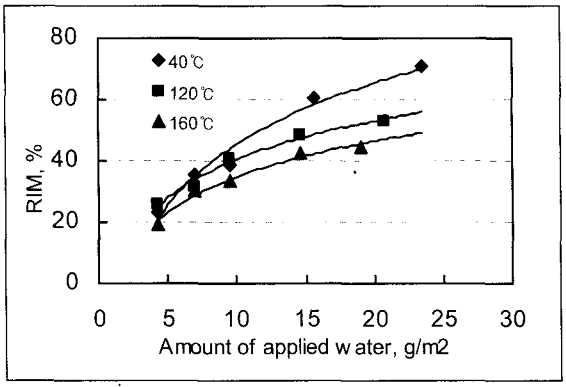

Fig. 4. Surface roughening of sheets calendered at the different temperature.

Evaluation of water penetration

Hot calendaring decreased the tendency of surface roughening of BCTMP sheet. It may be due to less fiber swelling or smaller penetration of water into fiber network. To evaluate which mechanism is dominant, the thickness and penetration depth of water in z-direction of sheet were determined using CLSM technique. Initial thickness of sheet after calendaring was depicted in Fig. 5. As calendaring temperature increases from 40°C to 160°C, sheet thickness decreases by 12%.

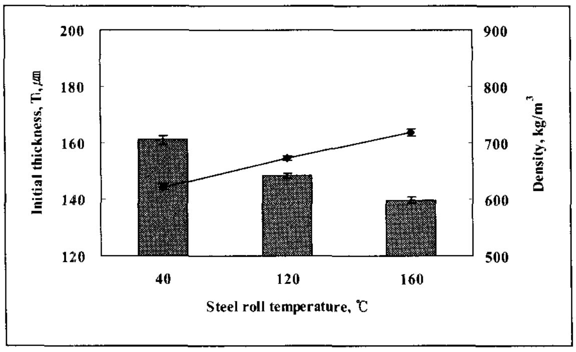

Fig. 5. Thickness of sheet after calendering.

Fig. 6 depicts sheet thickness after moistening as a function of the amount of applied water. Fibers and fiber network compressed by hot calendering were swollen by water and thickness was recovered. Increase of thickness has the linear relationship with water amount.

Stained thickness (Ts) consisted of penetration depth into fiber network and thickness change by fiber swelling. Therefore, the penetration depth was determined by subtracting thickness of unabsorbed (unstained) part from initial thickness of sheet (Fig. 7). Compared with uncalendered sheet, sheet calendered at low temperature (40°C) showed a deeper penetration of water. It seemed because of relatively smaller capillary induced by mild calendering (8). The lowest penetration of water was obtained when sheet was calendered at high temperature (160°C). According to Vreeland et al (19), heat in calendering was transferred to about 17% of thickness in z-direction at this condition. Because sheet was also calendered above glass transition temperature, sufficient deformation and densification could happen in top side of z-direction. That is to say, the reduction of pore by densification and permanent deformation hinders water from penetrating into fiber network and finally allowed less surface roughening.

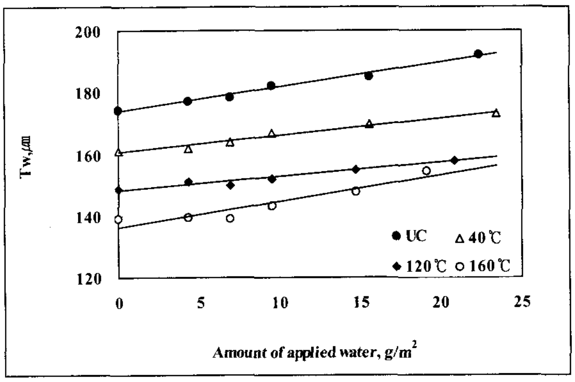

Fig. 6. Thickness of sheet after moistening.

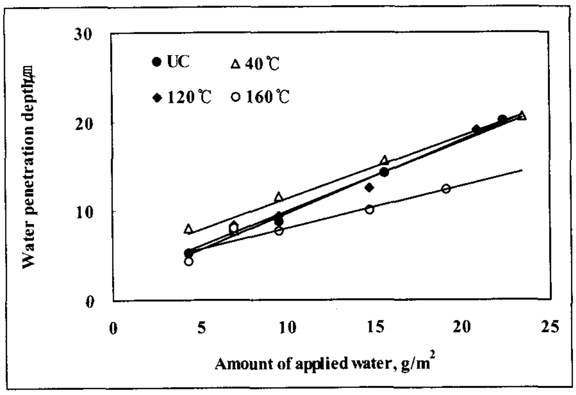

Fig. 7. Water penetration depth (L) in z-direction of BCTMP handsheet.

CONCLUSIONS

Surface roughening is one of causes to deteriorate surface properties of coated paper. It is occurred by interaction between base paper and water in coating color, and affected by pulp type, precalendering, and coating operation variables. In this study, effect of calendering variables on surface roughening of BCTMP sheet and the relationship between hot calendering and water penetration depth were investigated. High pressure calendering is beneficial to reduce surface roughness before coating but its smoothening effect is mostly lost by contact with water. On the contrary, sheet calendered at the highest temperature showed the lowest roughening. To examine the effect of hot calendering, water penetration depth was determined using CLSM technique. High temperature calendering above Tg allowed the small penetration of water into fiber network by sufficient deformation and densification in top side of z-direction of sheet. Consequently, hot calendering could be the effective way to reduce surface roughening and unevenness of paper surface.

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 Research Foundation.

REFERENCE

1. Salminen, P.J., Water transfer into paper-the effect of some liquid and paper variables, Tappi j. 71(9):195-200 (1988).
2. Hoc, M., Fiber rising in papers containing mechanical pulp, Tappi Journal 72(4):165-169 (1989).
3. Aspler, J.S. and Béland, M.-C., A review of fibre rising and surface roughening effects in paper, JPPS 20(1):J27-J32 (1994).
4. Gane, P.A.C. and Hooper, J.J., in Fundamentals of Papermaking, Ed. by Baker, C.F., vol. 2, MEP Publications, p. 871 (1989).
5. Skowronski, J., Lepoutre, P., and Bichard W., Measureing the swelling pressure of paper, Tappi J. 71(7):125-129 (1988).
6. Engström, G. and Lafaye, J.F., Precalendering and its effect on paper-coating interaction, Tappi J. 75(8):117-122 (1992).
7. Youn, H.J., Lee, H.L., Chin, S.M., and Lee, S.G., Effect of roughness and densification of precalendered sheet on surface roughening, in Proceeding of 58th Appita Annual Conference, Appita, p565. (2004).
8. Roberts, R.J., Senden, T.J., Knacktedt, M.A., and Lyne, M.B., Spreading of aqueous liquids in unsized papers is by film flow, JPPS 29(4):123-131 (2003).
9. Vreeland, J. H., Ellis, E. R. and Jewett, K. B., Substrata thermal molding, Part 1:A breakthrough in the understanding and practice of the hot calendering of paper, Tappi J. 72(11):139-145 (1989).