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Roughening Due to Ink Jet Rewetting: Effect of Paper Treatment and Composition

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Abstract. *An ink jet printer was used to deliver small quantities of ink-dyed water to laboratory handsheets having a range of compositions and treatments. An optical profilometer recorded initial and final roughness statistics at fixed locations on the printed surfaces. For paper made with chemical pulp, it was found that the relative change in local roughness after rewetting (change in roughness divided by initial roughness, $\Delta R_a/R_{ao}$) increased with the degree of calendering, beating, and the amount of surface and internal sizing. The corresponding changes in skewness and kurtosis after rewetting reflected the development of increased fiber rising. Increasing amounts of surface sizing produced larger $\Delta R_a/R_{ao}$, corresponding to an increase in the ink penetration depth. Rewetting produced the greatest $\Delta R_a/R_{ao}$ in paper manufactured with mechanical pulp, with $\Delta R_a/R_{ao}$ becoming smaller as the fraction of chemical pulp was increased to 0.4, after which it became insensitive to composition.* © 2008 Society for Imaging Science and Technology.
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INTRODUCTION

Interactions between ink and paper during printing can produce undesirable changes in the paper structure. Although there is a significant body of literature dealing with this subject, most previously published work has been devoted to large-scale rewetting of the entire sheet that leads to curl, wrinkle, cockle, and shrinkage.[1–3] These distortions of the fiber network are due to the nonuniform distribution of water, swelling of fibers, weakening of fiber-fiber bonds, and the release of internal stress. Relatively little work has been done to characterize the small-scale distortions resulting from highly localized surface rewetting by, for example, ink jet printing. In such cases where dry paper fibers surround and constrain the wetted area, there may be roughening of the surface and fiber rising, causing a loss of gloss and an increase in sheet friction.[4,5] These effects increase as more water is applied and absorbed, as the contact duration increases with increasing temperature and with increasing mechanical pulp content.[4,6,7] As with large-scale rewetting, the causes of these distortions are relaxation of stress, recovery of fiber shape, interfiber debonding and fiber swelling.[6–10] Plankinton[11] noted that paper samples containing mechanical pulp that were treated with a drop of fountain solution and dried at 149°C showed puffed and lifted fibers and increased roughness. Reme and Kure[12] found that moistening a sheet in a Prüfbau laboratory printing press produced an increase of 0.35 μm in average roughness in areas covered with fines and fillers, and an increase of 0.8 μm on areas containing mostly mechanical fibers. Mao et al.[13] examined the local changes in surface roughness and permanent swelling that accompany local ink jet rewetting of various coated and uncoated commercial papers with water. A scanning optical profilometer recorded permanent paper swelling in excess of 5 μm and average roughness changes greater than 1 μm.

Although these earlier studies provided much useful information concerning sheet roughening and the factors upon which it depends, they did not include a systematic investigation of the sensitivity of roughening to paper composition and treatments. The objective of the present work was to quantify the small-scale roughening, produced by ink jet rewetting with water; of handsheets having various levels of calendering, beating, surface and internal sizing; and mechanical and chemical pulp.

MATERIALS AND METHODS

To examine the effect of base sheet on the local roughness and swelling of paper, laboratory handsheets were prepared. Both beaten and unbeaten kraft pulps as well as blends of mechanical and chemical pulps were used in these experiments. Table I provides a list of samples and their method of preparation.

Sample Preparation

Three types of pulp were used in these experiments: a NIST standard kraft pulp (batch 8495), a commercial never-dried blend kraft pulp, and a commercial high yield aspen chemithermomechanical pulp (CTMP). Samples 1–8 (see Table I) use the NIST kraft pulp and Samples 9–20 use the commercial blend kraft pulp. Paper samples were lab-made handsheets using TAPPI standard method T 205 om-88 and

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Table I. Paper samples used in rewetting experiments (UC: uncalendered, LC, MC, and HC: low, medium and high levels of calendering, SS: surface sized, IS: internally sized, and B: beating, CTMP: chemithermomechanical pulp). In samples 1–8, the NIST kraft pulp was used, while in samples 9–20, a commercial kraft blend was used.

No.	Sample code	Calendering temp. (°C), load (kN/m), and number of nips	Kraft pulp (%)	CTMP pulp (%)
1	UC	NA	100	0
2	LC	80,100,2	100	0
3	MC	150,200,2	100	0
4	HC	160,500,10	100	0
5	SS(2%)+HC	160,500,10	100	0
6	SS(4%)+HC	160,500,10	100	0
7	IS+HC	160,500,10	100	0
8	B+HC	160,500,10	100	0
9	LC-1	92,100,1	0	100
10	LC-2	92,100,1	20	80
11	LC-3	92,100,1	40	60
12	LC-4	92,100,1	60	40
13	LC-5	92,100,1	80	20
14	LC-6	92,100,1	100	0
15	HC-1	160,500,10	0	100
16	HC-2	160,500,10	20	80
17	HC-3	160,500,10	40	60
18	HC-4	160,500,10	60	40
19	HC-5	160,500,10	80	20
20	HC-6	160,500,10	100	0

were stored in a controlled environment at 50%±2% relative humidity and 23±1°C overnight. To examine the effect of internal sizing, 0.5 wt% (based on the dry pulp) alkylketene dimer (AKD) and 1.0 wt% alum were added during the preparation of Sample 7. In addition, in order to study the effect of fiber fibrillation on the sheet rewetting, some of the NIST kraft pulp was beaten in a PFI mill at 8000 rev (Sample 8). Surface sizing was conducted in a laboratory flatbed coater (TMI, Montreal, Quebec, Canada) using either 0.2% or 0.4% (based on the slurry) cationic potato starch (Ciba Chemicals Canada Inc.). The surface treated samples were further conditioned overnight. After conditioning, handsheets were calendered using a laboratory supercalender (Beloit–Wheeler, USA) and reconditioned prior to testing.

Printing

The deposition of the liquid for rewetting was done using an HP 520 ink jet printer, which was modified so it could hold a glass microscope slide on which the paper specimens were mounted.[13] The ink in the cartridge was replaced by distilled water with 10% by volume HP 51625 black ink jet ink. The addition of this small amount of ink facilitated the identification of the printed areas using an optical microscope.

The amount of ink-dyed water applied to paper was obtained gravimetrically by weighing the ink cartridge before and after printing. Since the volume of ink-dyed water used for printing a line is very small, 40 lines with the size of 2.032 cm×0.0635 cm were printed for the gravimetric analysis. The liquid coverage (mass of liquid applied per unit area) used in this study was estimated as 15.5 g/m^2, and the mass of liquid deposited per unit line length was 9.8 g/m.

Microtopographic Measurements and Rewetting

A WYKO™ NT-2000 optical surface scanning profilometer was used for the topography measurements. This device had a scanning depth of 500 μm and a vertical resolution of 1 nm.

The rewetting experiments were conducted using the procedures developed earlier.[13] For each sample of Table I, three specimens (2 cm×3 cm) were tested and on each specimen three locations (each 603 μm×459 μm in size) were chosen for measurements; i.e., a total of nine locations were analyzed for each sample. The specimens were mounted onto microscope slides (76 mm×25 mm) using double-sided tape (Intertape brand®) and Post-it Notes® (3M Co.) to ensure the flatness of the paper specimen. The glass slide was positioned at a fixed location on the stage of the optical profiler, and three locations on the specimen, each 1 mm apart, were scanned. The specimen was then removed and positioned on the ink jet printer, and a two-point line (measured as a font size in Microsoft Word) was printed on the scanned location. After about a 10 min drying period, the slide was again positioned on the WYKO™ stage and the same three precise locations were rescanned to measure the effects of rewetting on the surface topography. For each location, arithmetic average roughness (R_a), root mean square roughness (R_q), skewness (R_{sk}) and kurtosis (R_{ku}) were determined before and after rewetting.[13] R_q is the standard deviation of the distribution of profile heights about the mean surface. The value of R_a compared with that of R_q reflects the nature of the surface, since, for a Gaussian distribution, $R_q/R_a=(\pi/2)^{0.5}\approx 1.25$.

Skewness is the third moment of surface height and is a measure of the asymmetry of the surface height distribution, while kurtosis indicates the relative level of peakedess (large hills and deep valleys) of the surface.

Ink Penetration

Printed paper samples were embedded in epoxy resin and microtomed using a Leica ultramicrotome until the printed line was reached. A digital image of the cross section of the sample was then acquired using a Leica DMLA microscope. The digital image of the sample was binarized using Optimas 6.0 software to better quantify ink penetration in the sample.

RESULTS AND DISCUSSION

The surface height profile of paper before and after two-point line printing of ink-dyed water was measured for the samples listed in Table I and results are summarized in Table II. As expected, local rewetting created local distortion of the

Table II. Roughness, skewness, and kurtosis before and after two-point line printing for samples listed in Table I.

	R_a, μm		R_q, μm		R_{sk}		R_{ku}	
Sample	Before	After	Before	After	Before	After	Before	After
UC	5.69	5.76	7.33	7.43	−0.55	−0.50	4.20	4.11
LC	4.30	4.89	5.71	6.45	−1.25	−1.11	5.62	5.15
MC	3.88	4.40	5.18	5.86	−1.24	−1.06	5.95	5.35
HC	2.97	3.64	4.11	4.95	−1.68	−1.36	7.64	6.65
SS(2%)+HC	2.20	3.06	3.13	4.20	−2.07	−1.14	10.38	6.88
SS(4%)+HC	2.14	3.32	3.22	4.54	−2.55	−1.33	13.44	7.32
IS+HC	2.81	3.75	3.86	4.99	−1.77	−1.33	8.57	6.82
B+HC	2.60	3.29	1.85	2.47	−2.20	−1.02	10.79	6.21
LC-1	2.89	5.33	3.98	6.89	−1.57	−0.63	8.79	4.34
LC-2	3.03	5.13	4.17	6.74	−1.64	−0.75	8.46	4.56
LC-3	4.77	6.80	6.31	8.74	−1.35	−0.86	6.53	4.71
LC-4	3.59	5.00	4.91	6.66	−1.81	−1.07	9.35	6.05
LC-5	3.73	4.80	5.07	6.50	−1.73	−1.49	7.67	7.25
LC-6	4.69	6.26	6.23	7.98	−1.51	−1.30	6.10	5.65
HC-1	1.58	3.08	2.58	4.38	−3.14	−0.57	24.40	8.26
HC-2	1.90	2.97	2.96	4.22	−2.75	−1.08	14.62	8.56
HC-3	2.45	3.39	3.63	4.69	−2.63	−1.28	13.32	7.76
HC-4	1.58	2.25	2.52	3.36	−3.12	−1.71	17.51	11.51
HC-5	2.49	3.38	3.56	4.63	−2.18	−1.15	10.70	6.67
HC-6	1.79	2.37	2.79	3.50	−3.07	−1.80	19.27	12.00

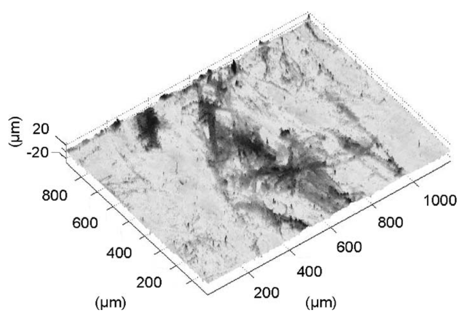

Figure 1. Permanent surface swelling due to ink jet printing of a two-point line on a commercial, internally sized uncoated paper as measured using an optical profilometer. Darker areas correspond to surface peaks.

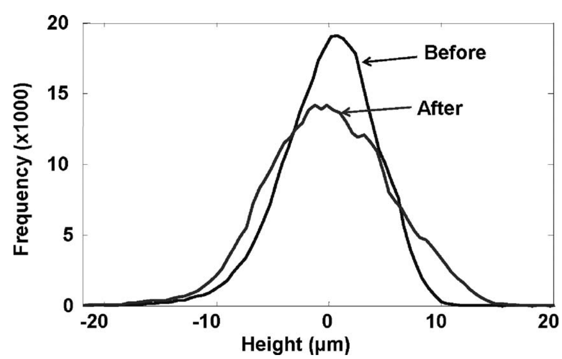

Figure 2. Histogram of surface heights before and after rewetting experiment for a commercial internally sized uncoated paper.

paper surface and altered the surface statistics. Figure 1 illustrates the change in the surface topography (or swelling) of paper after ink jet printing as measured using an optical surface profilometer. This image was obtained by subtracting the paper surface profile before and after printing. The largest increase in the surface height in this case was about 12 μm. An example of changes in the surface height distribution after rewetting experiment is given in Figure 2. After rewetting, the paper was rougher (broader histogram) and the surface height profile was more symmetrical (less skewed).

A close look at Table II shows that (1) skewness remained negative both before and after rewetting. This indicates that the topography of these samples was dominated by features below the mean surface ("holes"). (2) Kurtosis was greater than 3 both before and after printing, signifying that the histogram of profile heights had a sharper central peak and fatter tails than that of a Gaussian distribution, corresponding to a physical surface of generally constant height near the mean with a few large peaks and valleys.

The change in local roughness after ink jet rewetting was measured for handsheets prepared with chemical pulp as a function of the degree of calendering, surface sizing, internal sizing, and beating. Local distortions were quantified in terms of the changes in arithmetic average roughness, ΔR_a, relative roughness, $\Delta R_a / R_{ao}$ (change in roughness normalized by the initial roughness. R_{ao} is the "before rewetting" roughness in Table II), root-mean-square roughness, skewness, and kurtosis. The effect of furnish composition

Table III. Pairwise comparisons (t-test) for ΔR_a and $\Delta R_a/R_{ao}$ (latter result in parentheses) due to rewetting as a function of calendering (low, medium, high calendering), surface sizing (SS), internal sizing IS) and beating (B) for chemical pulp handsheets (samples 1–8 in Table I). Confidence level: ✓ > 95%, △ > 90%, ○ < 90%, — not applicable.

	LC	MC	HC	SS(2%)+HC	SS(4%)+HC	IS+HC	B+HC
UC	✓(✓)	✓(✓)	✓(✓)	—	—	—	—
LC		○(○)	○(✓)	—	—	—	—
MC			✓(✓)	—	—	—	—
HC				△(✓)	✓(✓)	✓(✓)	○(△)
SS(2%)+HC					✓(✓)	—	—
SS(4%)+HC						—	—
IS+HC							—
B+HC							

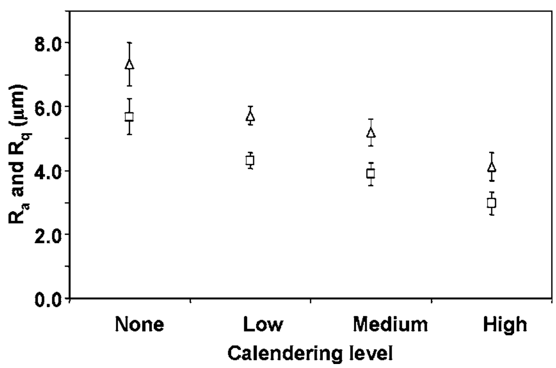

Figure 3. Initial R_a (□) and R_q (△) of calendered papers as a function of the level of calendering. Error bars represent 95% confidence intervals based on a total of nine repetitions on three specimens.

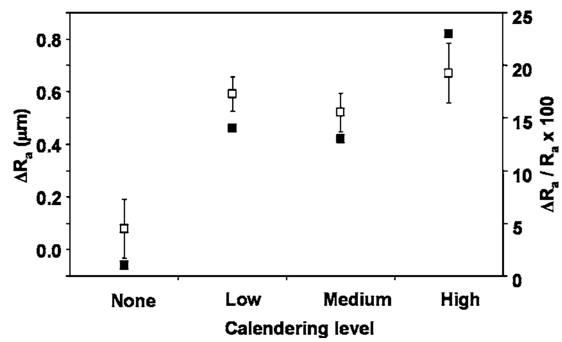

Figure 4. Absolute change (□) and % change (■) in average roughness as a function of calendering level. Two-point line rewetting with 10% ink-dyed water.

was also assessed using calendered handsheets made of varying proportions of mechanical and chemical pulps. Table III summarizes the statistical significance of the pairwise comparisons of ΔR_a and $\Delta R_a/R_{ao}$ among the various factor levels in the chemical pulp test matrix. It is seen that calendering, surface sizing and internal sizing, produced significant differences in the paper roughening response in certain cases. This result is examined in greater detail in the following sections.

Effect of Calendering

A series of papers with differing initial values of roughness was prepared by calendering. The roughness of paper decreased as the level of calendering increased, as illustrated in Figure 3. Each data point represents the average roughness of nine separate locations measured on three paper specimens. From Table II, the ratio of the initial value (before rewetting) of R_q/R_a increases from 1.29 for uncalendered sheet to about 1.38 for highly calendered samples, that is higher than 1.25 expected of a surface having a Gaussian distribution of profile heights.[13]

Figure 4 illustrates the absolute change and relative change in average roughness (R_a) due to rewetting for paper with various levels of calendering. The data points represent the average of ΔR_a and $\Delta R_a/R_{ao}$ for nine separate locations on three different paper specimens, and the 95% confidence intervals are shown for ΔR_a. The pairwise t-tests of Table III show that the change in roughness for uncalendered base sheet and all levels of calendering was significant at a confidence level of >95%. Similarly, high and medium calendering levels were significantly different; however, the difference between low and high calendering levels was insignificant. The reason for this apparent anomaly is unknown.

The increase in roughness after rewetting was expected since calendering locks in residual stress that is released upon rewetting. However, the change in roughness was smaller for lower calendering levels, and there was no significant change in the roughness of uncalendered paper after rewetting. This result is consistent with the observation of Grondin and Wood,[14] that pulps must be calendered if they are to be compared for their roughening tendency due to rewetting.

The observed local behavior was reasonably consistent with what has been found on the macroscopic scale.[9,10,15] For instance, Hoc[4] reported that the surface roughness of a calendered magazine paper increased by about 1 μm (as measured with a Parker print surf) after the action of moisture, heat, and bending.

Since the initial roughness of handsheets decreased with calendering, and because the degree of roughening was related to the initial roughness of the basesheet,[16] it is more meaningful to investigate the changes in roughness after rewetting in terms of the percentage change in roughness

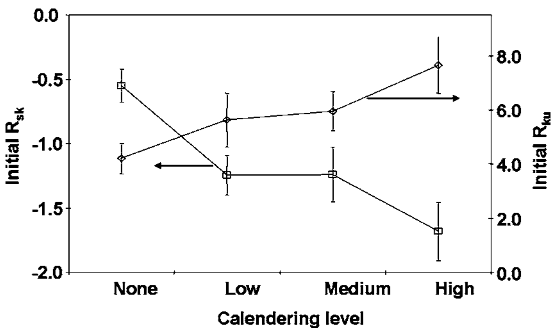

Figure 5. Initial skewness R_{sk} and kurtosis R_{ku} at different calendering levels. The error bars are the ±95% confidence intervals.

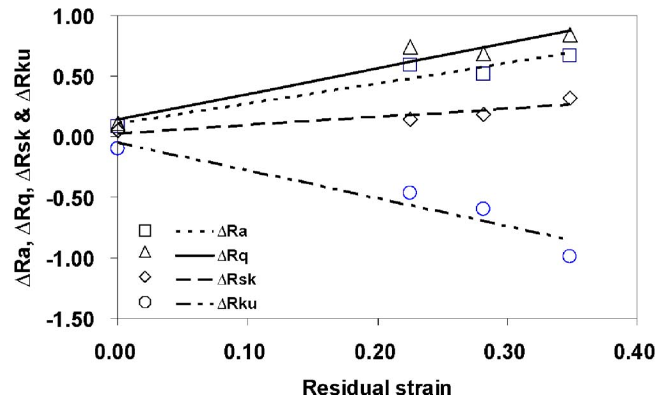

Figure 6. Relationship between transverse residual strain and changes in surface statistics resulting from rewetting. The four levels of residual strain correspond to the uncalendered, low, medium, and high calendered sheets.

($\Delta R_a / R_{ao} \times 100$). The results plotted in Fig. 4 indicate that the relative increase in roughness due to rewetting was generally greater for higher levels of calendering.

Skewness is a measure of the asymmetry of the surface profile about the mean line. As mentioned previously, a predominance of bumps or peaks on a surface is characterized by a positive skewness, while a predominance of holes or valleys in a surface yields a negative skewness (a smoother surface). Therefore, R_{sk} tends to become more negative as calendering flattens the peaks, as shown in Figure 5.

Kurtosis is a measure of the breadth of the probability distribution of the height profile about the mean line. The kurtosis value is large when the histogram of surface height has a sharp central peak and fatter tails a normal distribution, representing a surface where the material is generally of more uniform height but has a few high peaks and/or deep valleys. A perfectly Gaussian or random surface has a kurtosis of 3.

Figure 5 shows the initial skewness and kurtosis of different levels of calendered paper. The initial kurtosis values become progressively greater than 3 as the degree of calendering increases, indicating that the profile height probability distribution is becoming progressively narrower than a Gaussian distribution, but this happens in an asymmetrical way, i.e., while peaks are progressively flattened with increased calendering, valleys are not disappearing to the same extent.

From Table II, after rewetting the skewness values of all the paper samples increased (became less negative) while the kurtosis decreased, reflecting a shift to a more Guassian distribution of surface heights.

These observations are attributable largely to the residual transverse stresses created in a sheet as a result of calendering. Upon rewetting, these stresses are released. and collapsed fibers tend to recover their natural shapes,[17] leading to sheet roughening, fiber rising, and an increase in the number of peaks and, hence, an increase in R_{sk} (less negative). Figure 6 illustrates the relationship between transverse internal residual strain (change in sheet thickness due to calendering divided by initial thickness) and the changes in roughness, skewness, and kurtosis that occurred after rewetting.

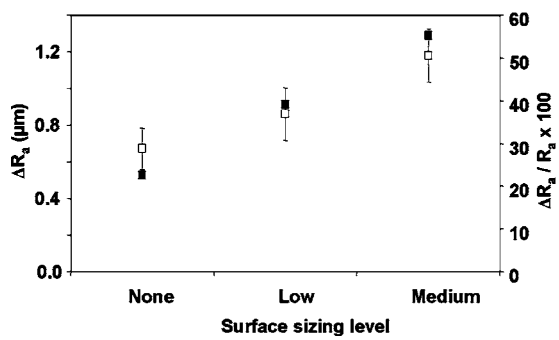

Figure 7. Absolute, ΔR_a (□), and relative, $\Delta R_a / R_{ao}$ (■), change in roughness as a function of surface sizing level. Error bars indicate ±95% confidence intervals based on nine measurements.

Surface Sizing

The initial roughness of paper samples decreased after surface sizing compared to unsized samples (Table II); however, there was no significant difference in the initial roughness of samples with different levels of surface sizing. The reduction in the initial roughness was expected as sizing agent is expected to fill the surface voids in the sheet. In addition, with increasing amount of surface sizing, the skewness values became more negative and kurtosis increased. Together, these two observations suggest that the shallow depressions are preferentially filled by sizing, leaving a surface clustered more closely around the mean height, but with a few deep valleys remaining. It should be emphasized that changes in the surface topography upon sizing may vary depending on the method of application (e.g., roll coating versus blade coating versus curtain coating). However, the effect of different sizing methods is beyond the scope of this study.

After rewetting, both the absolute and relative change of average roughness increased with the degree of surface sizing (Figure 7). Pairwise statistical comparison (Table III) shows that the effect of surface sizing on roughness change was statistically significant at 90% or more confidence level. Surface sizing lowers the surface energy of paper and increases the water contact angle, reducing spreading. It is hypoth-

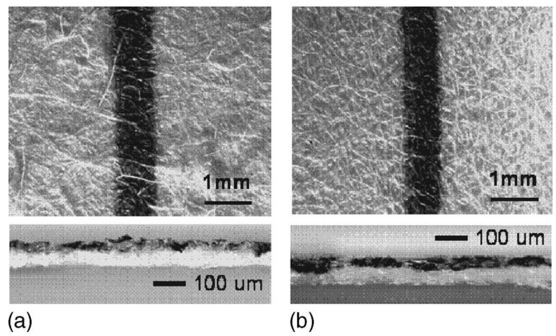

Figure 8. Micrographs of ink spreading (top row) and the cross-section image showing ink penetration (bottom row) for (a) HC sample and (b) SS(2%) + HC sample.

esized that the increase in the roughness change after rewetting with surface sizing level may be due to reduced lateral water spreading but increased penetration. This was investigated by measuring the width of the printed line on each paper and the depth of ink penetration by microtoming and examining the cross-section of samples. Figure 8 shows typical images used to determine the line width and ink penetration depth of samples and the data are summarized in Table IV.

The data of Table IV support the hypothesis that printed line width decreases and the ink penetration increases in the surface sized papers compared to the samples without sizing. To better illustrate this point, the previous data are plotted in Figure 9 showing that a larger ink penetration depth corresponded to an increased ΔR_a and ΔR_{sk}.

Interestingly, the differences in skewness and kurtosis values after rewetting for surface sized samples were not statistically significant, despite the fact that the initial values (before rewetting) were quite different. The reason for this is not known.

Internal Sizing

The data of Table II indicate that the initial roughness for internally sized paper (IS+HC) was smaller than unsized sample (HC), while the final roughness of these samples after rewetting was approximately the same. Therefore, the change in roughness was greater for internally sized paper (IS+HC) compared to unsized samples (HC). As with surface sized samples, the increase in ΔR_a can be attributed to reduced liquid spreading after internal sizing. However, Table IV shows that both the liquid penetration and spread were smallest on the internally sized paper. Given that the applied liquid volume was constant for all of the experiments of Table IV, this appears to contradict the observation with the other papers that penetration and spread vary inversely as a consequence of volume conservation. This paradox is explained by liquid evaporation, which was appreciable with the internally sized paper. For example, the time to absorption of a 0.012 ml ink-dyed water droplet was less than 0.5 s for unsized paper and more than 5 min for the internally sized paper (both high level calendered). As a result, liquid applied to the internally sized paper interacted with the surface fibers for a relatively long period causing

Table IV. Ink penetration and spreading on different paper samples (two-point line printing with 10% ink-dyed water).

Sample	Ink penetration (μm)	Line width (μm)
HC	34	780 ± 15
SS(2%)+HC	37	720 ± 10
SS(4%)+HC	41	720 ± 11
IS+HC	32	650 ± 5

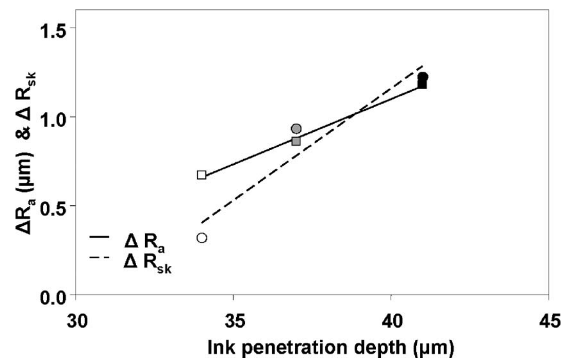

Figure 9. Changes in roughness (squares) and skewness (circles) as a function of ink penetration depth for samples with no surface sizing (white), sized with 2% solution (gray) and sized with 4% solution (black).

more surface roughening by stress relaxation and fiber rising. Note that the overall recovery of sheet thickness may be smaller for these samples, but the change in roughness depends primarily on the surface fibers for the length scales considered here.

In highly calendared paper, the internal sizing had no significant effect on the changes in skewness and kurtosis samples due to rewetting.

Beating

Paper made with beaten kraft pulp (B+HC) had a lower initial roughness than paper made with unbeaten pulp (HC); i.e., $R_a = 2.60$ μm (beaten) versus 2.97 μm (unbeaten). It is known that beating increases fiber collapse and conformability, thereby enhancing paper smoothness. However, beating did not produce a significant difference in the ΔR_a due to rewetting compared to the paper made with unbeaten fibers (Table III). Since the initial roughness of (B+HC) samples was smaller, the relative change in roughness for the beaten samples was about 10% larger than that of unbeaten samples with 90% confidence level (Table III).

Furthermore, using beaten fibers caused the initial skewness to become more negative and kurtosis to increase (Table II), implying that beating led to a smoother surface having a narrower distribution of profile heights compared with the HC paper. After rewetting, however, the difference in surface statistics for these samples was not statistically significant.

Effect of Furnish

A commercial never-dried kraft pulp (70% HW and 30% SW) and a commercial high yield pulp (aspen, 300 CSF)

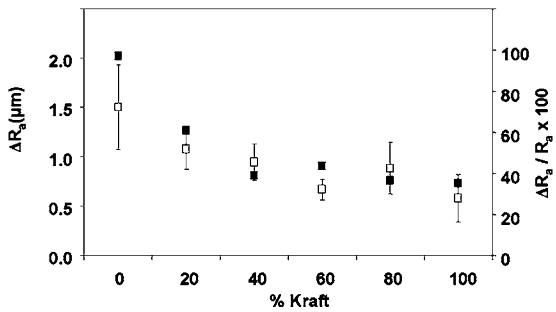

Figure 10. Increase in the average roughness ΔR_a (□) and relative roughness change $\Delta R_a/R_{ao}$ (■) after local rewetting as a function of the fraction of kraft pulp in sheets made from blends of kraft and chemithermomechanical pulps, for samples with high level calendering (samples 15–20 in Table I).

Table V. Pairwise comparisons (t-test) of data presented in Fig. 10. Confidence level: ✓ > 95%, △ > 90%, ○ < 90%.

Kraft%	20	40	60	80	100
0	○	✓	✓	✓	✓
20		○	✓	○	✓
40			○	✓	△
60				○	○
80					△

were blended to make handsheets with varying furnishes. These handsheets were calendered at two levels of calendering (samples 9-20 in Table I) and analyzed using the procedure described earlier.

Figure 10 shows that, for the high calendering level, the change in roughness after rewetting was greatest for samples prepared from 100% high yield pulp, and ΔR_a decreased as the fraction of kraft pulp increased up to 40%. Above this limit, ΔR_a seemed to be insensitive to the sheet composition. However, pairwise comparison using the t-test showed that the change in ΔR_a with increased kraft content was not always statistically significant (Table V).

With the exception of the sample made from 100% CTMP, there was no significant difference between ΔR_{sk} and ΔR_{ku} for samples with various kraft contents.

The change in roughness for samples with low level calendering (samples 9–14 in Table I) was similar to those with high level calendaring, i.e., an increase in the proportion of mechanical pulp led to a greater change in the surface roughness after rewetting.

The larger roughness change for samples made of high yield pulp fibers may be attributed to the higher lignin content and, therefore, the increased stiffness of these fibers. On rewetting, such mechanical-pulp fibers may undergo a larger relaxation, producing a greater change in surface roughness and fiber rising compared with paper from kraft pulp.

CONCLUSIONS

The local roughness changes due to ink jet rewetting of laboratory handsheets having a range of compositions and treatments were measured using an optical profilometer. For paper made with kraft pulp, it was found that the relative change in local roughness (change in roughness over initial roughness, $\Delta R_a/R_{ao}$) increased with the degree of calendering, beating, and the amount of surface and internal sizing. Papers that were not calendered had a substantially larger initial roughness, which tended to mask the roughness changes due to rewetting. In all cases, rewetting and roughening caused the skewness to become less negative, reflecting an increase in the relative proportion of profile peaks, while a decrease in kurtosis indicated a shift to a more Gaussian distribution of surface heights. For papers made with mixtures of chemical pulp and 60% or more mechanical pulp, relative roughening increased with the fraction of mechanical pulp. However, below 60% mechanical pulp the relative roughening was unaffected by the relative amounts of chemical and mechanical pulp.

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