Predicting printability of LWC-rotogravure paper through variability analysis

Harri Sundell, Mikko Likitalo, and Kristiina Raita

ABSTRACT: Four lightweight coated papers with slightly different coatings were subjected to a wide range of conventional laboratory measurements prior to printing in a commercial rotogravure press. Printed samples were evaluated by professional printers, and their subjective evaluations were compared with the laboratory analyses. Visual assessment of print quality by professional printers showed only a rough correlation with results from the conventional laboratory methods that are used to predict print quality (Parker print-surf and heliotest). However, a new testing device (Tapio paper variability analyzer) that measures the vertical roughness of paper gave results that showed good correlation with visual assessment of print quality.

KEYWORDS: Coated papers, lightweight papers, printability, quality, rotogravure papers, test methods, variability.

Conventional methods of evaluating paper quality provide limited information about the factors that affect print quality, making it difficult to predict printability. In many cases, these difficulties can be traced to the fact that paper is not a homogeneous material, resulting in samples that are not representative of the product. Under these conditions, it is hard for the mill to identify which process parameters need to be adjusted to obtain better print quality.

This article examines the use of statistical analysis as a tool for quality development and focuses on product consistency as one of the key characteristics for printing papers.

Theoretical

Cutshall (*1*) discussed paper variation in detail, identifying four distinct categories. These ranged from long-term variation of more than 200 s to variation of less than 100 mm at the level of paper formation. This report focuses on the very-short-term variation that occurs at the level of formation and extends the concept of variation to variability, which better reflects the nonuniform physical characteristics of paper as related to printability.

Figure 1 shows caliper variation over a 250-mm span on a paper sheet as measured by the Tapio paper variability analyzer (Tapio Technologies Inc., Finland). The spiked curve is the caliper measured across the sheet segment, and the smooth curve is a filtered average with a preset maximum wavelength of 100 mm. The filtered average is continuously displayed on the analyzer screen. The caliper in Fig. 1 varies between 72 μm and 80 μm over the 250-mm span (60–310 mm). This variation is converted to variability by subtracting the average caliper from the measured caliper, as seen in **Fig. 2.**

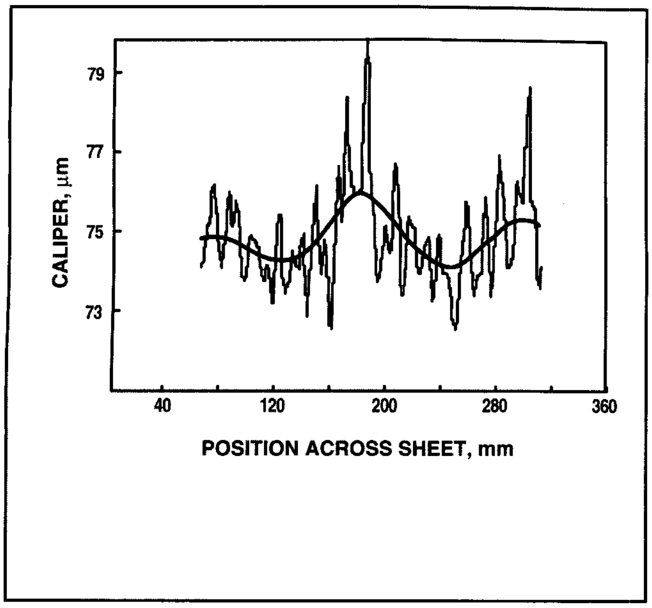
Using the Tapio analyzer, it is possible to set four threshold values and calculate how long the signal resides above or below these values. This is demonstrated in **Fig. 3**, which shows a portion of the caliper variability signal. In this case, the maximum wavelength used was 30.0 mm, thus filtering out variability longer than 30.0 mm. The overshoots for each threshold value are then classified by length in categories with 0.8-mm steps (0–0.8, 0.8–1.6, 1.6–2.4, etc.).

Figure 4 shows the distribution curves for each of the four threshold values. For example, the distribution curve for "avg. caliper +1 μm" (the top curve in Fig. 4) peaks at approximately 6% and 1.6 mm. This peak indicates that approximately 6% of the tested sites across the sheet contained "flocs" that were 1 μm thicker than the average paper thickness and 0.8–1.6 mm in length.

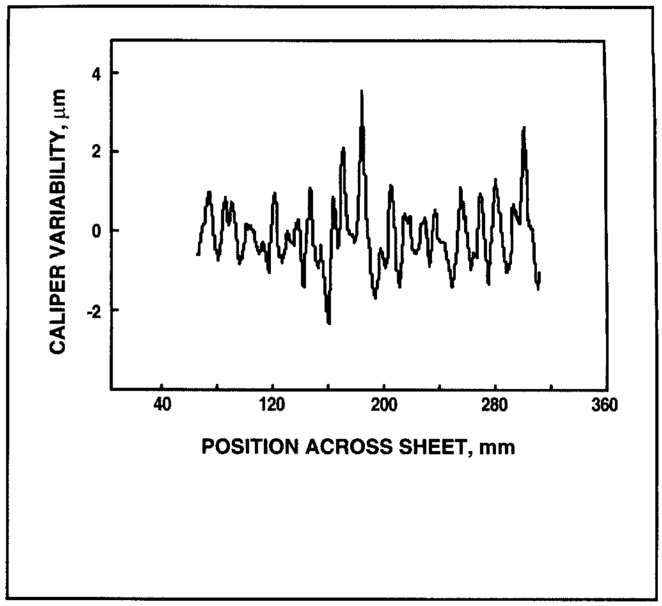
The distributions also can be drawn in a cumulative manner, as seen in **Fig.** 5, which shows the cumulative percentages for all four categories. For example, the number 16.5% on the top line indicates that 16.5% of the paper is composed of flocs that are 1 μm thicker than the average paper thickness.

Sundell is a production manager at Helprint Oy, SF-50101 Mikkeli, Finland. Likitalo, R&D director, and Raita, laboratory engineer are affiliated with United Paper Mills, Ltd., SF-26101 Rauma, Finland.

1. Caliper variation across a 250-mm span. The original caliper signal is shown in absolute scale. The solid sine wave is a filtered average



2. Caliper variability across a 250-mm span. The signal reveals only very-short-term fluctuations of ±2 µm.



Experimental

Four lightweight coated (LWC) papers from coating-application experiments on two paper machines were printed in four colors on a commercial rotogravure press. Prior to printing, these papers were thoroughly tested in an effort to determine which paper analyses provided the best prediction of paper printability.

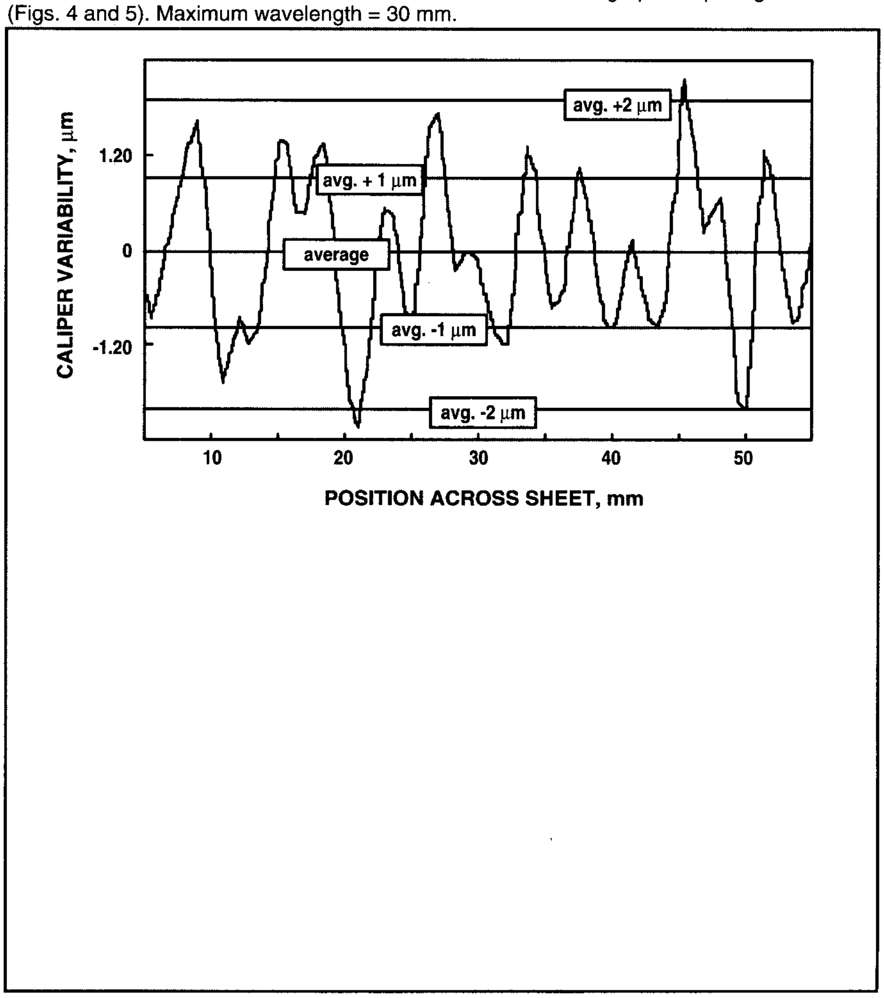
Unprinted paper samples

Laboratory measurements. Samples of unprinted paper were subjected to routine laboratory measurements. Results are listed in **Table I**.

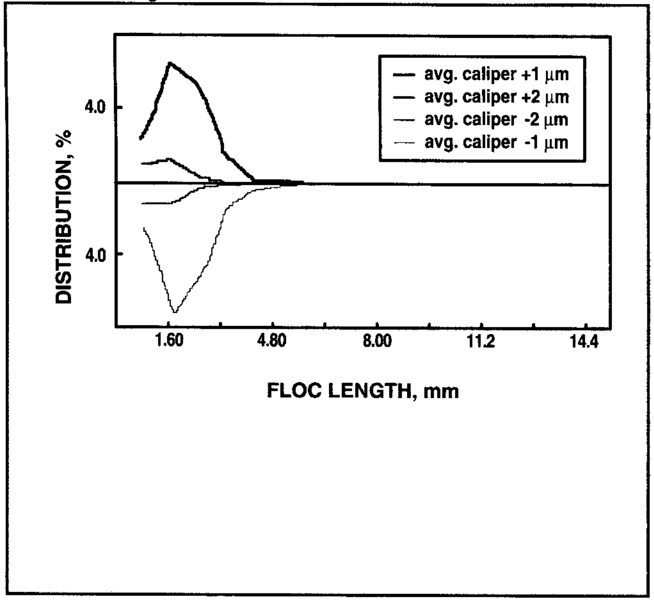
Variability measurements. The Tapio variability analyzer used in this study runs paper strips 8-in. wide both from machine-direction (MD) samples (1000–6000 m long) or cross-machine direction (CD) strips (1–50 pieces) taped together. **Figure 6** shows the analyzer in use at a paper mill.

The MD samples provide information over a wide range of variation, from the very-high-frequency variations associated with paper formation to the lower-frequency variations associated with other paper machine operations. Special programs are available to pre-

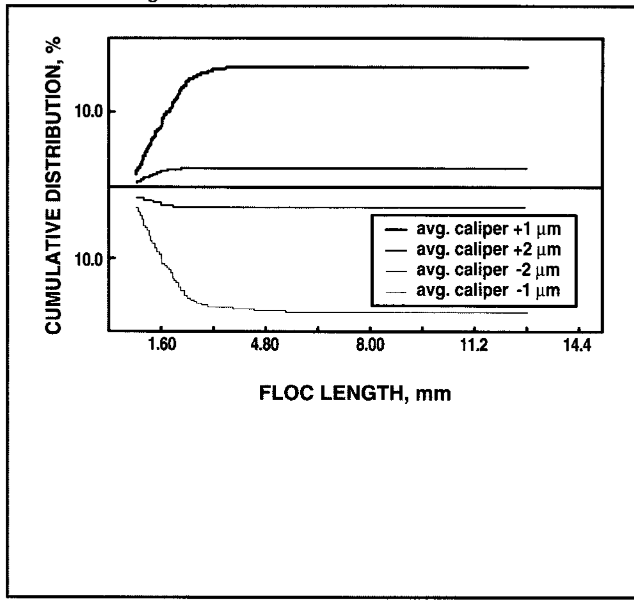
3. Caliper variability signal with four superimposed threshold limits. The length of each overshoot or undershoot is recorded and classified for use in graphs depicting "floc sums" (Figs. 4 and 5). Maximum wavelength = 30 mm.



4. Length distribution of paper flocs for the four caliper thresholds. Maximum wavelength = 30.0 mm; lowest floc length = 0.8 mm; class size for floc length = 0.8 mm.



5. Cumulative distribution of paper flocs for the four caliper thresholds. Maximum wavelength = 30.0 mm; lowest floc length = 0.8 mm; class size for floc length = 0.8 mm.



I. Laboratory results for the four LWC printing papers

Property	Paper samples 1	2	3	4
Printer's evaluation	7.5	8.5	8	7
Basis weight, gm²	61.2	61.2	63.7	58.8
Caliper, µm	51	51	52	50
Density, kg/m³	1202	1202	1225	1178
Tensile index (MD), kN/m	2.52	2.58	2.65	3.06
Tensile energy absorption, J/m²	17.2	17.7	18.4	21.6
Stretch at break (MD), %	1.1	1.1	1.1	1.1
Tear (CD), mN	254	245	253	232
PPS S-10 (top side), µm	0.46	0.48	0.44	0.69
PPS S-10 (bottom side), µm	0.55	0.56	0.46	0.89
Gloss (top side), %	66.6	71.2	72.9	65.2
Gloss (bottom side), %	62.3	64.1	68.0	63.6
Brightness (top side), %	72.1	73.1	73.4	71.5
Brightness (bottom side), %	72.4	73.6	73.1	71.8
Luminance (top side), %	76.6	78.6	79.0	76.8
Luminance (bottom side), %	76.9	78.9	78.7	77.0
Opacity (top side), %	91.9	91.4	92.1	91.2
Opacity (bottom side), %	91.7	92.0	91.9	91.3
Wavelength (top side), nm	575.0	575.5	575.9	575.8
Wavelength (bottom side), nm	547.9	575.6	575.7	575.8
Excitation purity (top side), %	4.2	4.9	4.9	4.8
Excitation purity (bottom side), %	4.2	4.7	5.0	4.7
Ash, %	36.7	32.6	38.4	33.4
K&N ink receptivity (top side), %	9.8	10.7	12.0	10.8
K&N ink receptivity (bottom side), %	9.9	11.5	10.7	11.5
Heliotest (top side), mm	82	79	79	40
Heliotest (bottom side), mm	109	110	106	35

dict long-term (1–4 miles apart) interactions of two or more process fluctuations. Information from MD samples is useful in diagnosing problems on the paper machine.

The CD samples provide information about sheet profile on the submillimeter level. Information from CD samples can be used to analyze paper machine performance and to calibrate on-line sensors used by the paper machine control system.

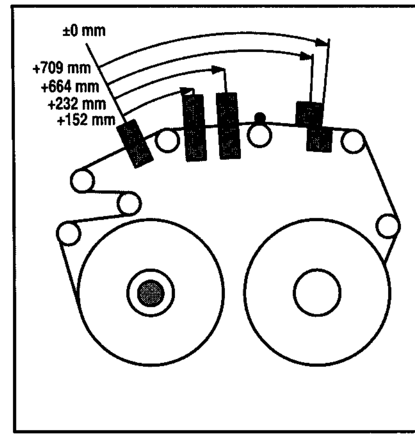
The variability analyzer has five different sensors that continuously measure the paper sample as it unwinds from one roll to another, as seen in **Fig. 7**. The sensor openings are relatively small:

- Basis weight = 5-mm diam.
- Light transmission = 1-mm diam.
- Gloss (both sides) = 4 mm x 4 mm
- Caliper ≤ 1-mm diam.
- Microprofiler ≤ 80-µm diam.

The precise distances separating the sensors are known, so the analyzer can allocate the various measurements to the same locations on the paper. This allows calculation of derived units, such as paper density from basis weight and

6. Tapio paper variability analyzer in use at a paper mill in Finland

7. Distances between sensors are determined automatically and stored by the computer program.



caliper. The measurement steps used were 800 µm, 100 µm, and 25 µm, and the measurement speeds of the paper web were 0.5 m/s and 0.2 m/s.

CD measurements. Tapio analyses in the CD were made by taking the paper remaining on the printing machine reels (approximately 4 cm of paper) and taping the 20 CD samples together. Extra paper was taped to both ends for the acceleration and braking phases on the test device. Signals from the tape enable the analyzer to separate the taped samples from each other. Results are computed and printed automatically.

Each of four sensors (basis weight, caliper, light transmission, and gloss) was used to conduct the following analyses: CD profiles, distributions, and paper machine stability profiles. The minimum wavelength in CD profiles was set to 10.0 mm.

MD measurements. Approximately 150 m of each paper was analyzed with regard to floc sums using the same four sensors (basis weight, caliper, light transmission, and gloss) together with an optical microprofiler sensor (*2*).

Very-short-term variations in paper quality from rapidly changing conditions during formation were analyzed. Longer-term variations also were analyzed to detect the periodic fluctuations in paper quality that occur from equipment vibration, blending of furnish components, basis-weight control, and other machine operations. The results for the longer-term variation are not presented here because they are not useful in predicting print quality. However, the longer-term variations did elucidate the behavior of the coating blades with applications of different coating colors.

Printing

Papers were printed during commercial production of advertising material on a rotogravure printing press (2240-mm wide). The four papers were printed sequentially under similar conditions. The major printing parameters are listed in **Table II**.

Printed paper

Five random samples of each of the four printed papers were selected for quality analysis. Apart from the technical measurements of printed papers, the printers themselves analyzed the papers visually and evaluated them on a numerical scale. The major criteria in the printers' evaluation were:

- Number of missing dots
- Number of "micro-holes" (partially printed dots)
- Print gloss
- Brightness
- General appearance of the printed image.

In this final criterion, the printer does not look at any details. Accordingly, this is the most important quality parameter, since all other quality parameters are included in this general evaluation. **Figures 8 and 9** show the print images that were evaluated and the types of print defects that were observed.

Results

Results of all laboratory analyses were compared with the printers' estimates, with emphasis on the quality of the printed surface.

Conventional laboratory tests

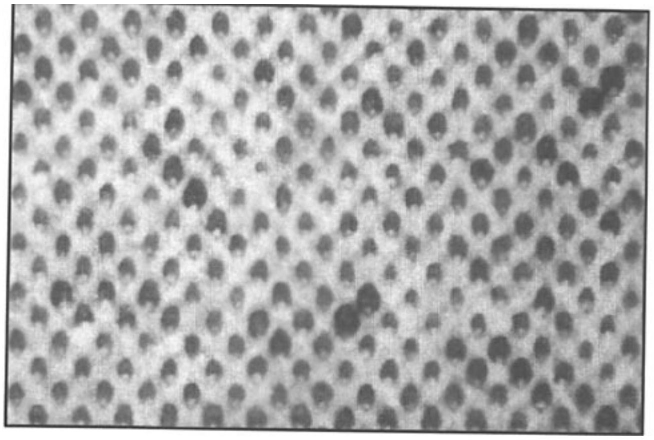
The results in Table I show that while the conventional laboratory tests on unprinted paper provided a general idea of expected print quality, none was able to arrange the samples according to the printers' evaluations.

Heliotest and Parker print-surf

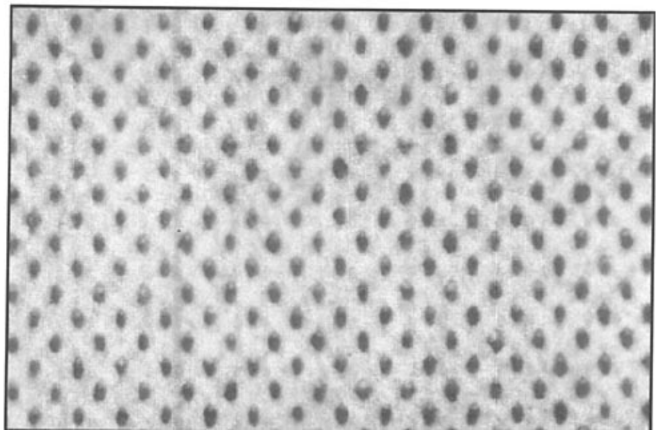
Neither the heliotest nor the Parker print-surf (PPS) provided results that could be correlated with the printers' results. While both methods predicted that Sample 4 would give the worst printing result, neither was able to predict information of print quality when quality differences were small.

Despite the small diameter of the annulus (*3*) used in PPS measurements,

8. Print image A with typical defects



9. Print image B with typical defects



II. Printing conditions

Printing job:	advertising magazine
Printing press:	Albert Frankenthal TR 6 B
Machine speed:	10 m/s
Printing pressure:	10 kN m/m^2
Printing inks:	commercial high-quality rotogravure inks
Color sequence:	yellow–magenta–cyan–black

roll, and the nip pressure, machine
speed, and ink used during the test

III. Heliotest results from CD profiles, mm

Position no.*	Measurement no. 1	2	3	4	5	6	7	8	9	10
					Sample 1					
1	82	93	94	95	92	85	94	87	103	91
10	88	93	87	88	96	87	97	85	91	93
20	98	98	110	106	109	94	100	106	88	110
					Sample 2					
1	73	81	78	101	90	72	77	84	99	70
10	74	75	84	80	82	80	101	81	94	94
20	87	84	93	78	99	70	73	83	82	85
					Sample 3					
1	75	80	74	80	74	88	90	85	88	68
10	70	64	71	71	71	68	73	78	84	73
20	85	79	88	88	70	81	73	88	91	67
					Sample 4					
1	38	42	37	35	40	37	38	37	39	30
10	30	41	36	36	28	36	30	38	33	35
20	30	33	27	29	31	26	33	27	30	36

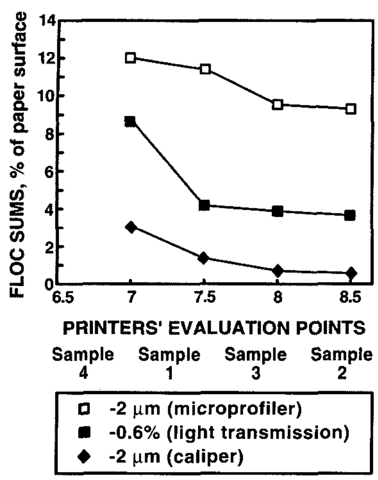
*Position nos. 1 and 20 are from opposite ends of the paper strip; position no. 10 is from the middle of the paper strip.

the method is incapable of providing results that reflect the combined effect of surface structure, compressibility, and color uptake (*4*). The lack of correlation between the heliotest and the actual printing run could be the result of several factors. The heliotest's backing roll was softer than the printing roll, and the nip pressure, machine speed, and ink used during the test were different from those used on the commercial printing press. Heliotest results also show high deviation from one measurement to another because of the variations in the paper surface. Therefore a great number of tests would be required to achieve a representative mean value of the paper quality. **Table III** lists the heliotest results from the CD profiles of the four LWC papers.

Tapio floc sums

Table IV shows the printers' overall evaluation along with the floc sums obtained using the variability analyzer. The correlation between the floc sums and the printers' evaluation was higher than for the conventional laboratory methods. Since the printers' evaluation is based on several different criteria, one type of measurement cannot provide the same amount of information. **Figure 10** shows that the percentage of thinnest spots (2 µm less than average thickness) and the percentage of the least transparent flocs (0.6% less

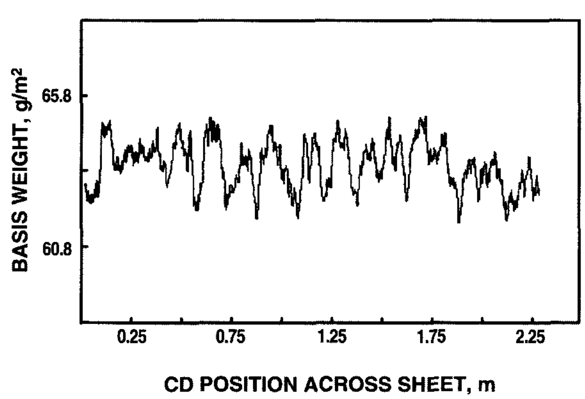
10. Correlation of floc sums and printers' evaluation for four LWC papers. The thinnest (2 μm less than average thickness) and the least transparent flocs (0.6% less than average light transmission) correlate directly with the printers' evaluation.



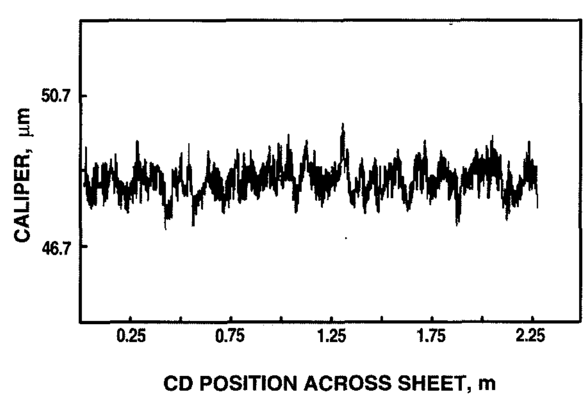
IV. Comparison of floc sums (% of paper surface) and the printers' subjective evaluation

	Microprofiler thresholds, μm				*Printer's points*
	+2	*+1*	*-1*	*-2*	
Sample 1	10.7	27.6	26.0	11.5	7.5
Sample 2	8.7	25.9	24.2	9.4	8.5
Sample 3	8.7	25.8	24.3	9.6	8
Sample 4	11.4	28.4	26.8	12.0	7
	Caliper thresholds, μm				
	+2	*+1*	*-1*	*-2*	
Sample 1	2.9	15.3	15.5	1.4	7.5
Sample 2	2.0	13.3	12.6	0.6	8.5
Sample 3	2.3	13.5	12.7	0.7	8
Sample 4	5.6	18.4	19.4	3.0	7
	Light-transmission thresholds, %				
	+0.6	*+0.3*	*-0.3*	*-0.6*	
Sample 1	5.0	19.7	20.2	4.3	7.5
Sample 2	4.6	19.2	19.4	3.7	8.5
Sample 3	4.4	18.9	19.5	3.9	8
Sample 4	9.2	24.1	25.5	8.7	7

11. CD profile of basis weight (based on 17 samples). Minimum wavelength = 10.0 mm; average = 63.2 g/m²; range = 3.5 g/m².



12. CD profile of caliper (based on 17 samples). Minimum wavelength = 10.0 mm; average = 48.3 μm; range = 2.7 μm.



than average light transmission) match with the printers' evaluation. Both parameters probably contribute to visual perception of print quality.

CD profiles

Because paper is printed in the longitudinal direction, the CD profiles do not serve printability prediction unless they exhibit uniformity. Therefore, floc sums were not computed in the CD. However, the uniformity of the CD profile was checked with regard to basis weight, caliper, gloss, and light transmission. The gloss and the caliper profiles followed the shape of the basis weight profiles, indicating good condition of the supercalenders. Variability in CD profiles can also explain one part of the deviation in heliotest results.

Figures 11 and 12 are CD profiles of basis weight and caliper, respectively, for one of the tested samples. Each profile is composed of 47,812 single measurements (using a sample step of 0.8 mm).

Conclusion

This study was carried out to determine whether the printability of slightly different LWC papers could be predicted from analysis of unprinted paper. Four LWC papers were subjected to a wide range of conventional laboratory measurements prior to printing in a commercial rotogravure press. Printed samples were evaluated by professional printers, and their subjective evaluations were compared with the laboratory analyses.

None of the conventional laboratory tests showed a strong correlation with the subjective evaluations. However, a recently developed five-sensor paper variability analyzer that measures paper variability in terms of "floc sums" did show correlation with the judgment of the printers. Because human perception of print quality depends on several different phenomena, further study is required to determine the combination of Tapio floc sums with the greatest correlation.

Literature cited

1. Cutshall, K., Tappi J. 73(6): 81(1990).
2. Makkonen, T., U.S. pat. 4,773,760.
3. Parker, J. R., Tappi J. 64(12): 56(1981).
4. Von der Heyde, H., Wochbl. Papierfabr. 110(1): 17(1982).

The authors extend their gratitude to Tapio Makkonen of Tapio Technologies, Inc., for help in elucidating the theoretical aspects of the floc sums and for lending the experimental microprofiler used in this study.

Received July 15, 1991.

Accepted April 14, 1992.

Presented at the TAPPI 1992 Coating Conference.