Print Gloss Development of Offset Ink on Controlled Coating Structure

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Abstract

Print gloss is an important attribute of the final printed product. While past work has looked at the influence of key aspects of the coating structure on print gloss, a systematic study has not been reported. The coating roughness, porosity, and pore size are changed by using various combinations of coating materials and by calendering against rough plastic sheets. The print gloss is measured every tenths of a second right after printing, a few minutes after printing, and a few days afterwards. Roughness and porosity affect the print gloss for the first two seconds: this result shows that they influence the ink-film splitting event. Once ink film starts to level, roughness and pore size influences the level of print gloss within the first ten seconds after printing. Porosity modifies the evolution of print gloss for the next few minutes. The decrease in gloss at long times is found to correlate to surface roughness.

***Keyword**: roughness, pore structure, pore size, pore volume, porosity, gloss, print gloss, coating, mechanism.

Introduction

Paper gloss, opacity, brightness and print gloss have been the subject of much research because of their strong influence on end-use performance such as image clarity, contrast, and resolution. Specular reflectionfor rough surfaces was described as a function of surface roughness, refractive indexes, and the wavelength of light[1]. Since most of components in paper coatings have similar refractive indexes, gloss is a strong function of roughness[2]. Like paper gloss, print gloss is determined by the final surface roughness of the ink film because ink components have similar refractive indexes.

Many different variables and processes influence the roughness of the ink film such as printing conditions, ink properties, leveling, film shrinkage, and the packing of ink components. Substrate roughness limits print gloss but the characteristics of the ink and its penetration may be primary factors in the micro-roughness region[3),4]. Large pore sizes and low porosities are found to give high print gloss [5]: these results seem to be caused by slow setting rates that lead to a long time for the film split pattern to level after printing. Xiang and Bousfield (1998) presented a modified pore absorption model that predicts large pores to cause slow setting[6]. Desjumaux and Bousfield (1998) developed a model of leveling based on porous substrate and compared with experimental result[7]: the leveling event influences print gloss such that smaller pores with fast setting stops the ink film leveling. However, the effect of substrate roughness was not studied.

In earlier work, pore size, pore volume, and roughness have been identified as important factors that determine print gloss. However, their combined-competitive influences have not been addressed in a systematic way. A better understanding of the print gloss dynamics should help guide coating formulations, printing conditions, and ink formulations to optimize the final product. Therefore, this work focuses on reporting the significance and characteristics of these different structural effects, even for short and long time gloss. Model samples are generated to isolate the structural factors each other and printed in the laboratory tester with dynamic glossmeter, and the monitored results will be discussed.

Materials and Methods

Gloss level was measured at 75° according to TAPPI Test Method (T 480 om-92). A glossmeter(micro-Tri-gloss, BYK Gardner) was used to measure gloss at 60°. The recommended range for 60°gloss is from 30 to 70 gloss units, therefore when the reading at 60°geometry is below 30 gloss units, 75° gloss is better to differentiate the samples in question. This glossmeter meets the standard requirements of ISO 2813, which is for 'Paints and vanishes' and also applicable to ink. It should be noted that there is no one standard for 'printed paper' though ISO 2813 comes nearest to a form of standard. For both instruments, gloss was measured on the samples grounded back with black non-glossy paper, otherwise noted.

The gloss of the ink film printed on the coated samples was measured immediately after the printing nip, using the technique[8)] described by Glatter and Bousfield (1997). A specially designed glossmeter, directly mounted on a laboratory printing press, recorded the ink gloss evolution every tenth of a second. A laser light source (675 nm, 1.0 mW, M38, 920, Edmund Scientific) was mounted and adjusted to 66° from the vertical, at which the glossmeter produced 9.98 Volts readings close to its maximum of 10 Volts from the surface of 98 gloss units at 75°, while generating enough signal from very low gloss samples away from its minimum 0 Volts. The size of the light spot on the sample was adjustable and configured to 13 mm (light direction) × 7 mm (cross light direction). Samples were attached to the printing plate with double-sided adhesive tapes. The flatness of plates was checked every ten printing tests and measuring area on the plate was adjusted to a certain location. Reading on the base itself without a sample was also checked every time before printing. Gloss at 60° and 75° was measured before and right after recording dynamic gloss. The configuration gave a coefficient of variation of around 15%.

A mechanical stylus profilometer was used to characterize roughness (Alpha-Step 200, Tencor). Two scan lengths of 80 ㎛ and 400 ㎛ were used with sampling rate of 25 points/㎛ and 5 points/㎛ respectively, with a force of 7 mgf. The area of 15 mm x 15 mm was scanned at least ten times. Roughness is defined in terms of deviations from the mean value. The arithmetic average roughness a is the average value of the deviation absolute value. The root-mean square(rms) roughness is the square root of the average deviation squared. No filtering was applied. No marking of the sample with the stylus was noticed after the tests.

The pore size distribution was measured using mercury porosimetry(Poresizer 9320, Micrometrics, USA). From the pressure and the intrusion volume data, a pore size distribution is obtained assuming the Young–Laplace equation. A surface tension of 485 dyne/cm and contact angle of 130°are used to calculate pore size from pressure.

The printing test was performed using a laboratory printability tester(KRK, Japan). The printing conditions are summarized in Table 1. The ink was a typical commercial cyan quick–set ink (Capiplus III Process Cyan, Flint Ink Co., USA). The density of ink was about 1.0 g/cm^3. The samples were allowed to condition in the test room for several days at 23℃ and 50% relative humidity prior to printing. After printing with various amount of ink, the print gloss data was extracted based on a certain amount of transferred ink on samples using interpolation. In most cases, the ink transfer ratio ranged from 20 to 49% and decreased with increasing the amount of ink feed on roller. Print gloss was obtained at 1.5~2.5 g/m^2 of transferred ink weight and reported at 2.0 g/m^2 ink level on the samples.

Table 1. Experimental printing conditions.

Parameters	Experiment I
Nip load, kgf/cm	25
Speed, m/s	4
Printing roll type(Width in cm)	Rubber (4)
Inking on roll (cc)	0.3, 0.5

Sample coatings were made on polyester film using laboratory draw–down coater. The grammage and roughness of base film was 112.5 g/m^2 and 2.3 ㎛, respectively. Pigments are summarized in Table 2 and the roughness of rough substrates for sample surface modification is given in Table 3. A target pH of 8.5~9 was obtained using 5 % solution of sodium hydroxide (NaOH). Solid contents were checked by drying and set near 63%.

Table 2. A summary of pigments used. Particle sizes are from manufacturers.

Pigment Code	Type	Particle size (㎛)
G1-0.3	GCC	0.30 (96% < 2㎛)
G2-0.4	GCC	0.44 (95% < 2㎛)
G3-1.5	GCC	1.50 (60% < 2㎛)
P1-0.4	PCC- Aragonite	0.40
P2-0.6	PCC- Rhombohedral	0.60
P3-0.57	PCC- Prismatic	0.57

Table 3. PPS roughness of substrates used for roughness modification during calendering. 'PE' and 'SP' refer to polyester and sandpaper respectively.

Code	PEN	PE1	PE2	PE3	PE4	PE5	PE6	SP1	SP2	SP3
Roughness Ra (㎛)	NA	1.4	1.6	2.1	2.3	4.7	4.8	8.1	9.0	9.5

The pigments were formulated with various levels of styrene butadiene(SB) latex binder(cp620na, Dow Chemical Co., USA) from 10 to18 pph(parts per hundreds in weight) in order to change the coating porosity, with 14 pph as the base case. Various combinations of coated samples and rough materials were processed through calendering(matte calendering). Calendering temperature was 65℃ and the speed was low to maximize dwell time of the samples in the nip. Calendering loads were changed from 123 to 215 kN/m. At least two nip passes were found to give better roughness transfer. The prepared samples and their properties are summarized in Appendix. Each sample is analyzed to find its mean pore location using mercury porosimeter such that a single pigment series with different porosity will have a certain median pore size. It is difficult to obtain the same pore size distribution, but by matching the median pore size, a reasonable comparison between samples can be obtained.

Results and Discussions

Extremely rough and low gloss surfaces were obtained with sand papers, while matte to high gloss region was controlled with polyester films. Sand paper was found to alter the pore size distribution a small amount, but the samples are still of use. Figure 1 shows the pore structure of the samples calendered with different polyester films. The mean or peak pore sizes a(㎛) itioning almost at the same location though there is bit of change in pore volume with the sample No.6. Physical properties of these three samples are shown in Table 4, where the pore volume is given for unit coat weight. These results confirm that roughness can be changed with the polyester films without changing the pore size or volume.

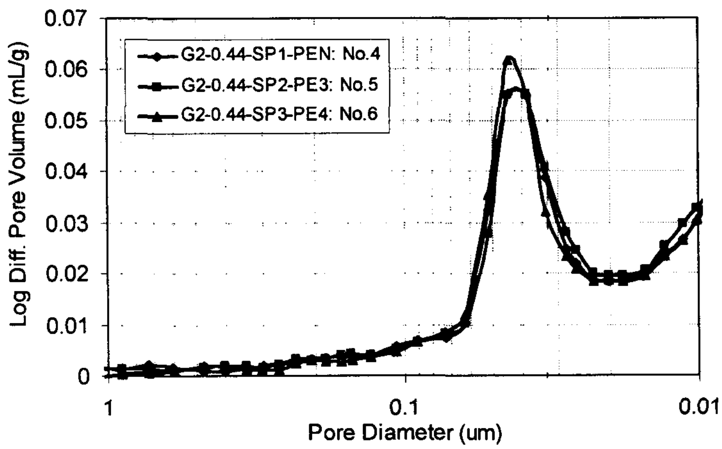

Fig. 1. Pore size distribution of samples calendered with different combination of rough materials (sand paper + polyester film).

Table 4. Pore structure characteristics and properties of the samples calendered with different combination of rough materials (sand paper + polyester film).

Samples		Roughness Ra (μm)	75° Gloss	Pore diameter at peak (μm)	Pore Volume below 1 um (mL/g)
No.	Code				
4	G2-0.44-SP1+PEN	0.258	51.7	0.040	0.136
5	G2-0.44-SP2+PE3	0.320	43.6	0.040	0.141
6	G2-0.44-SP3+PE6	0.284	48.1	0.042	0.136

The relationship between measured stylus roughness and paper gloss is presented in Figure 2. Even though there was relatively large variation in roughness values, the relationship was found good enough to be used except some extreme regions. Thereby, gloss may be used as roughness indicator as expected.

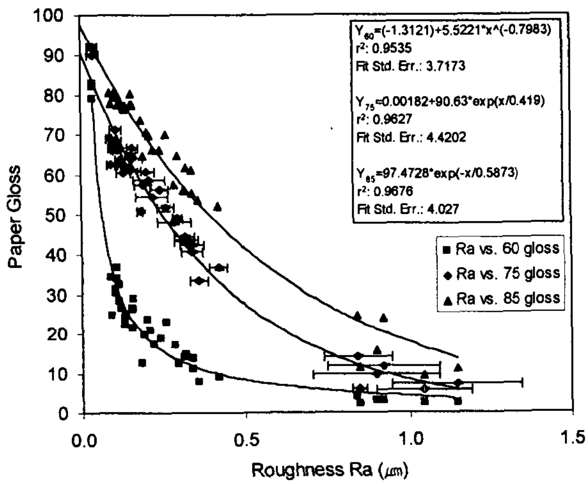

Fig. 2. The relationship between measured roughness and paper gloss.

Figure 3 is the relationship between the voltage from the dynamic glossmeter and conventional gloss meters at 60° and 75° geometry. As expected, the relation between dynamic gloss and conventional 60° gloss was rather linear due to their geometrical similarity.

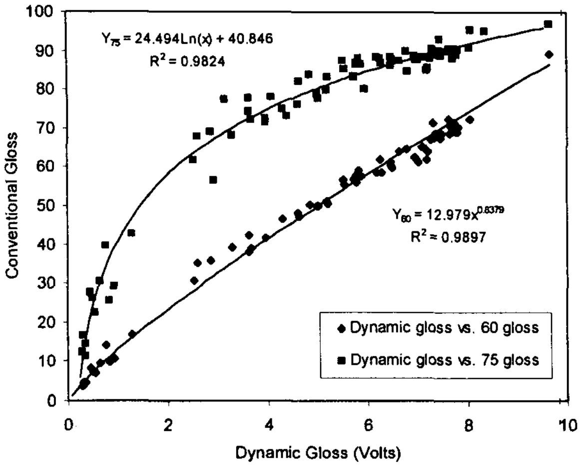

Fig. 3. The relationship between laboratory dynamic gloss meter and conventional 60° and 75° gloss.

The observed coating structures and the print gloss are summarized in the Appendix. The presented roughness is the arithmetic mean average value Ra over a 400 ㎛ tracking length from stylus profilometer. Void characteristics are the converted values for a coated layer without compressibility correction. The representative values for one sample will be used for the samples with the same coating formulation but different roughness.

Influence of Roughness on Print Gloss

The effect of coating roughness and paper gloss on print gloss is given in Figures 4 and 5, respectively. The pore size and volume are also shown in the legends of the figures. The roughness of paper influences the print gloss for the whole range of parameters, even when the ink film thickness was larger than the roughness. The significant difference in print gloss level at the same roughness can be explained by looking at the pore size or pore volume. The G1 series with the smallest pore size produced the lowest print gloss, while G2 series with larger pore size but similar pore volume had higher print gloss. This result agrees with past results and may be explained in terms of the setting rate compared to the leveling rate. This interpretation also expands to the case of P1, P2, and P3 series though it was hard to distinguish P2 from P3 in terms of their structure. Another noticeable result was the behavior of G2−1 series with the smallest porosity. This series showed relatively high print gloss at 300 seconds after printing, but it was reduced after several days. The distinct feature of this series was its low porosity and it is the only one treated with the combination of 'sand paper and polyester film' in this comparison group. Therefore, slow setting on a rough surface might result in relatively high initial print gloss but a low gloss after some time.

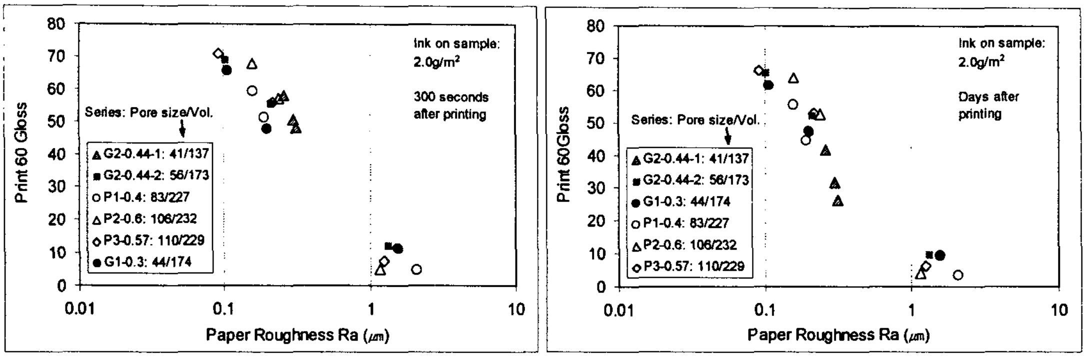

Fig. 4. Influence of roughness on print gloss at 300 seconds(up) and at several days(down) after printing. Pore size and volume in the legend are in terms of μm and μℓ/g.

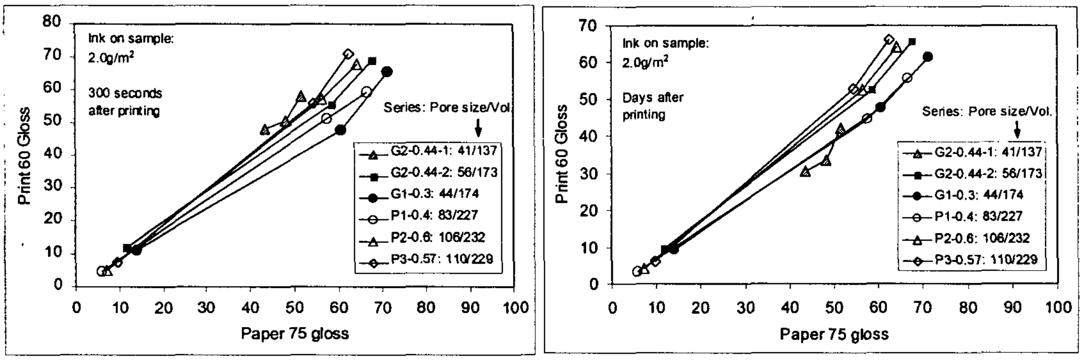

Fig. 5. Print gloss 300 seconds(up) and several days(down) after printing as a function of unprinted paper gloss.

Figure 6 shows the print gloss development on various rough coatings. The effect of roughness was again consistent with the results of the final gloss. The 'critical gloss rise' time to 90% of maximum was in the same ranking as coating gloss. However, the dynamic gloss was restricted by roughness level. When the result was plotted in a log scale of time, as in the right side of Figure 6, the roughness is seen to influence the gloss right after printing. Therefore, the roughness level of the coating influences the ink film split event. The amount of ink fed into the printing nip should not influence the results because the ink transfer ratio was similar to each other and the transferred ink amount was held constant for comparison.

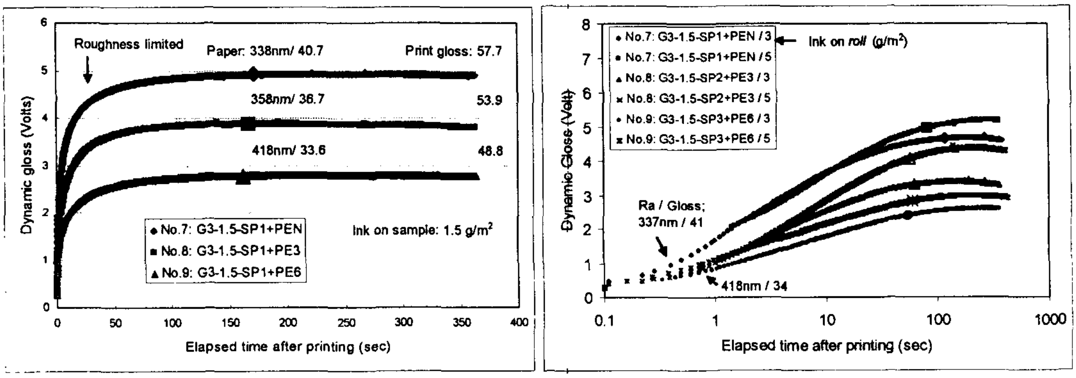

Fig. 6. Dynamic print gloss as a function of time (up) and log-scaled time (down). No.7~9 of G3 series. Note that inking amounts are based on the roll.

Effect of Porosity at Constant Roughness

The pore size distribution for the pigment series G2 is shown in Figure 7. Even though the pore size is not strictly constant as the latex level increases, the shift of the pore size distribution peak is not large for a given pigment. Despite the shift, there is still a significant overlap of the pore size distributions. Figure 8 shows the print gloss of these samples. The gloss trends are as with past work in that as porosity increases, the print gloss decreases. Again, the setting rate compared to the leveling rate explains this result: high porosities increase ink setting rate giving less time for ink leveling. Large gloss decreases were observed for samples that were calendered with a combination of sand paper and polyester film.

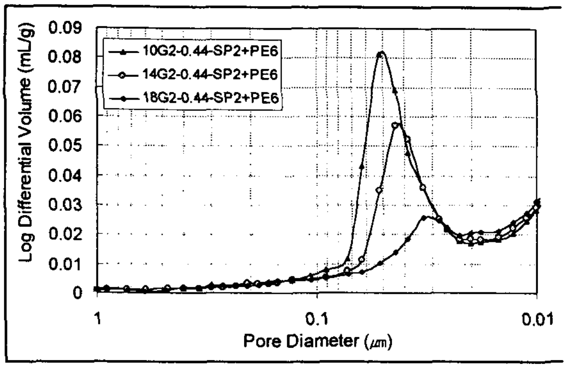

Fig. 7. Pore structures of the samples with various binder contents. Pore volume is for the sample itself.

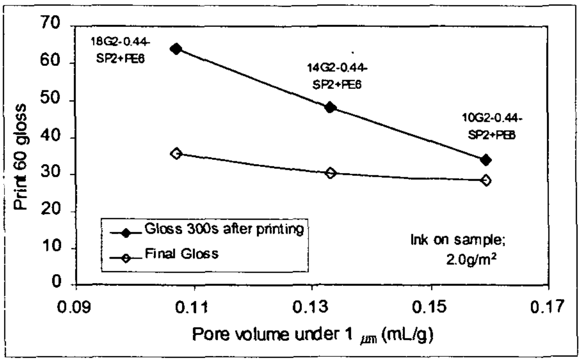

Fig. 8. Effect of porosity on print gloss at constant roughness. Roughness ranges from 315 to 337 nm (gloss at 75: 42.4 ~ 44.6%).

The behavior of print gloss development for different porosities, shown in Figure 9, is different from that of roughness in that the porosity effect at short times was reversed order compared to the final gloss result at long times. The low initial gloss for a less porous surface may be caused by larger splitting pattern formation as noted by Glatter[9]. The initial difference may also come from different amount of ink supply, because when the binder level increases, the transfer of ink decreases, and more ink needs to be fed into the nip. This behavior of poor ink transfer was also noted by Zang and Aspler[10]. However, there are cases in the data below that have similar ink film thicknesses, but different initial gloss levels. Within ten seconds, the dynamic gloss of each sample followed in a consistent order with their final print gloss. In summary, small porosities seem to produce larger filaments that level slowly at short times, but small porosities result in slow setting and long times for leveling to give high gloss at long times.

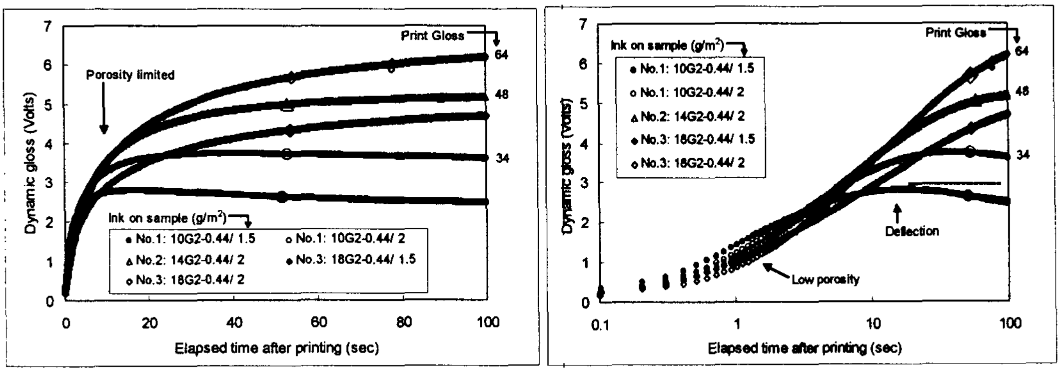

Fig. 9. Print gloss development as a function of time (left) and log-scaled time (right) and porosity

Effect of Pore Size at Constant Porosity and Roughness

Samples with similar roughness and porosity are sorted out. Their structures and print gloss are given in Figures 10 and 11, respectively. The similarity between samples No.15 and 18 as well as No.22 and No.25 made it possible to find the effect of pore size. Roughness ranged from 110 ~ 210 nm (75 paper gloss; 58 ~ 67%), pore size from 44 ~ 110 nm, and pore volume (below 1 mm pore size) from 0.034 ~ 0.46 mL/g. As expected, an increase in print gloss was observed as pore size increased. Sample No.35 deviates from No.15 and No.18 for lower roughness and porosity. The different level between (No.15 and 18) series and (No.22 and No.25) series can be explained by their porosity difference despite of larger roughness of the first group. One thing to note is that the sample No.33 and No.35 had almost the same print gloss despite of their different structure; the high print gloss of No.35 was thought to come from low roughness and porosity, while that of No.33 mainly resulted from large pore size. However, this competitive result may not be interpreted in a quantitative way at this time.

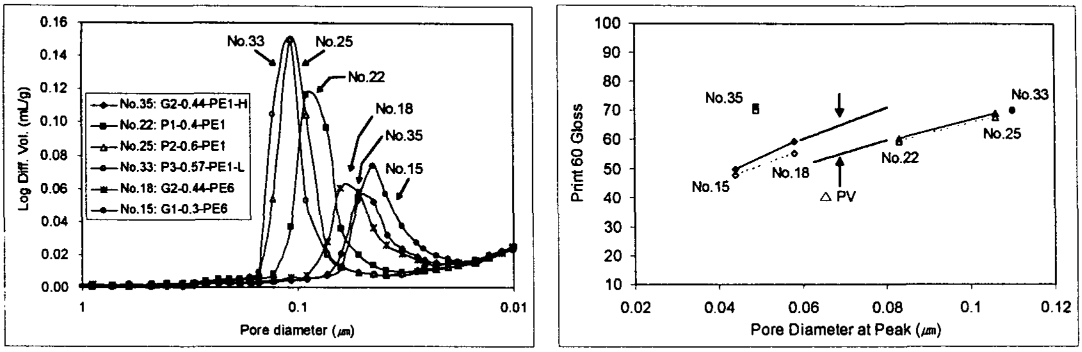

Fig. 10. Pore structure of the sorted samples for pore size effect. Porosity is for the sample itself.

Fig. 11. Effect of pore size on print gloss at similar roughness and porosity levels.

The effect of pore size was clear in that the larger the pore size, the higher the print gloss. However, pore size did not show a significant influence on the initial gloss. Figure 12 shows the gloss dynamics for these selected samples. Even though the gloss goes to different levels at long times, the initial gloss seems to be the same. Therefore, the pore size does not seem to influence the film.split event.

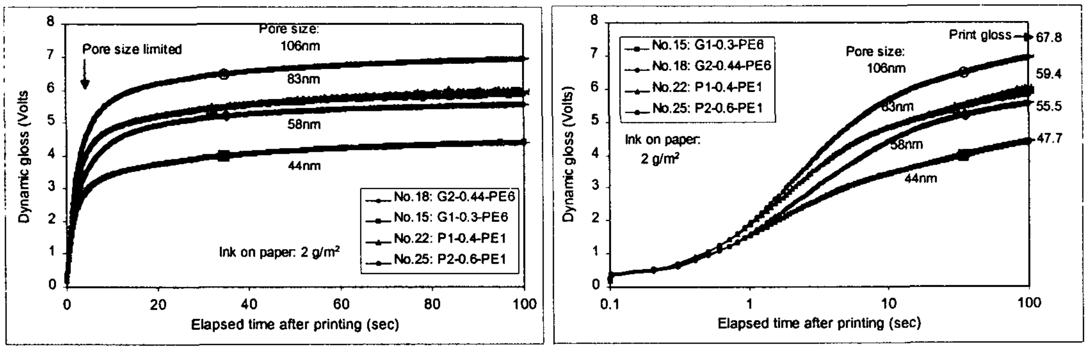

Figure 12: Print gloss development as a function of time (left) and log-scaled time (right) and pore size.

Gloss Reduction

The decrease from the gloss over a longer period of time was seen. The roughness of the coating layer was the major structural parameter for this gloss reduction: large roughness gives a larger drop in gloss. Several reasons could exist for the gloss reduction such as film shrinkage, protrusion of ink components, extended movement along with coating surface, or a film forming around pigments. However, because the results correlate with roughness, the shrinkage of the ink film explains the results: thick regions of the leveled ink film shrink more than the thin regions to generate surface roughness. Resin components may move from the top of the ink film surface along with solvent, resulting in a more rugged surface with ink pigments[11]. This mechanism does not necessarily correlate with coating roughness. A conceptual illustration is given in Figure 13. Only a large enough coating roughness may cause this contouring and significant gloss reduction. The deflection time will also vary depending on the other factors such as pore structure.

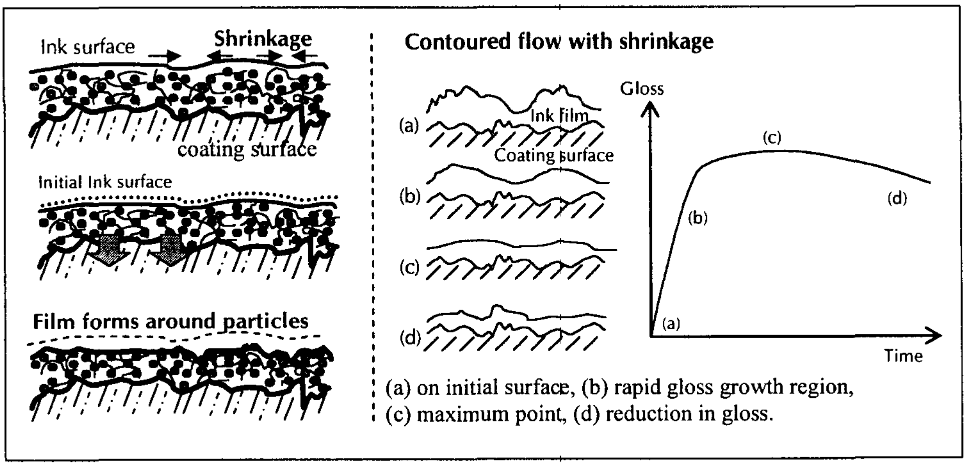

Fig. 13. A conceptual illustration on gloss decrease in time.

Conclusions

The behavior of print gloss development was measured with respect to the structural factors of the coating layer. Roughness modification was possible with a simple calendering technique(matte calendering) with little change of the pore structure.

- Roughness influences print gloss from the ink film splittingstage and had consistent effect even down to the small (100 nm) microroughness region with high inking levels.
- Low porosity coatings give high initial roughness or lower print gloss, but results in slow setting rates that lead to long leveling times and high gloss. Pore size does not seem to influence the ink film splitting, but large pores do give higher print gloss.
- Rough coating layers correlate with a significant decrease in gloss at long times. This decrease may be linked to the ink film shrinkage, but more work is needed to verify this mechanism.

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Appendix. Summary of Prepared Samples and Their Surface Properties.

SAMPLE		Roughness (um)	Paper Gloss		Pore Dia. at Peak	Pore Vol (<1 um)	Total Int. Vol.	Print Gloss after	
			60°	75°					
No.	Code	Ave.	Ave.	Ave.	(㎛)	(mL/g)	(mL/g)	300s	days
1	10G2-0.44-SP2+PE6	0.337	13.7	42.4	0.050	0.159	0.212	34.0	28.5
2	14G2-0.44-SP2+PE6	0.314	14.2	43.4	0.042	0.133	0.195	48.0	30.5
3	18G2-0.44-SP2+PE6	0.315	14.8	44.6	0.032	0.107	0.179	64.0	36.0
4	G2-0.44-SP1+PEN	0.258	23.0	51.7	0.040	0.136	0.185	58.0	42.1
5	G2-0.44-SP2+PE3	0.320	14.0	43.6	0.040	0.141	0.187	55.4	34.6
6	G2-0.44-SP3+PE6	0.284	17.0	48.1	0.042	0.136	0.192	50.6	33.6
7	G3-1.50-SP1+PEN	0.358	11.2	40.7	-	-	-	57.7	-
8	G3-1.50-SP2+PE3	0.337	7.7	36.7	-	-	-	53.9	-
9	G3-1.50-SP3+PE6	0.418	8.9	33.6	-	-	-	48.8	-
10	G3-1.50-PEN	0.154	21.6	61.2	-	-	-	-	-
11	G3-1.50-PE3	0.181	12.5	50.9	-	-	-	62.7	-
12	G3-1.50-PE6	0.294	12.3	49.2	-	-	-	51.6	-
13	G3-1.50-SP2	0.850	2.1	5.9	-	-	-	10.1	-
14	G1-0.30-SP2	0.841	4.0	14.1	-	-	-	11.2	9.5
15	G1-0.30-PE6	0.201	23.8	60.7	0.044	0.174	0.214	47.7	47.5
16	G1-0.30-PE1	0.107	36.7	71.4	-	-	-	65.7	61.5
17	G2-0.44-SP2	0.922	3.1	11.7	0.058	0.173	0.233	12.3	9.8
18	G2-0.44-PE6	0.209	21.0	58.6	0.058	0.176	0.213	55.5	52.5
19	G2-0.44-PE1	0.101	31.4	67.7	0.052	0.169	0.210	68.9	65.5
20	P1-0.40-SP2	1.045	2.4	5.8	-	-	-	4.6	3.4
21	P1-0.40-PE6	0.190	19.9	57.6	-	-	-	51.1	44.5
22	P1-0.40-PE1	0.158	29.0	66.7	0.083	0.227	0.267	59.4	55.6
23	P2-0.60-SP2	1.147	2.5	7.1	-	-	-	5.0	4.1
24	P2-0.60-PE6	0.239	18.9	56.4	-	-	-	57.1	52.6
25	P2-0.60-PE1	0.158	26.4	64.2	0.106	0.232	0.274	67.8	64.1
26	P3-0.57-SP2	0.899	3.0	9.7	-	-	-	7.5	6.1
27	P3-0.57-PE6	0.217	17.4	54.4	-	-	-	55.7	52.9
28	P3-0.57-PE1	0.092	24.9	62.4	-	-	-	70.8	66.1
29	G1-0.30-PE1-L	0.105	34.0	68.5	-	-	-	56.3	57.4
30	G2-0.44-PE1-L	0.101	30.4	66.4	-	-	-	72.0	65.9
31	P1-0.40-PE1-L	0.154	26.6	65.1	-	-	-	65.9	59.5
32	P2-0.60-PE1-L	0.131	24.4	62.4	-	-	-	69.3	65.7
33	P3-0.57-PE1-L	0.131	22.6	60.6	0.110	0.229	0.274	70.1	64.4
34	G1-0.30-PE1-H	0.086	34.3	69.3	-	-	-	61.7	60.7
35	G2-0.44-PE1-H	0.114	32.5	66.9	0.049	0.160	0.191	69.7	64.8
36	P1-0.40-PE1-H	0.112	28.4	66.1	-	-	-	62.3	58.6
37	P2-0.60-PE1-H	0.120	26.6	63.8	-	-	-	69.0	64.7
38	P3-0.57-PE1-H	0.135	25.2	62.1	-	-	-	67.8	63.8