MECHANISMS OF PRINT GLOSS DEVELOPMENT

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ABSTRACT

In nip printings like offset, print gloss was dependent on coating materials (acrylonitrile groups content and gel content of latex), coating formulation (latex content), coating structure (pore volume and smoothness), printing conditions (speed and linear pressure) and ink conditions (ink volume on plate and tackiness). Those factors affected ink transfer, ink holdout, magnitude of an initial split pattern and penetration rate of the vehicle controlling the ink viscosity. These mechanisms were exemplified by continuous print gloss measurements immediately after printing and by continuous observations with a video microscope. Additionally, three-dimensional shape of dried ink film printed on paper was measured with a confocal laser scanning microscope. It showed that stripes looking white in video images were valleys with gentle slopes on both the sides. It was found using a freeze-drying technique that valleys generated in printing become shallow with time. Printing (threading) direction, MD or CD, also affected print gloss. Anisotropy in ink solvent absorption into a coating somehow due to fiber orientation of the base paper was suggested to cause print gloss anisotropy.

INTRODUCTION

Glossy printed matter create luxury atmosphere. Therefore, print gloss is one of the important factors to determine the print quality. In particular, for high-grade coated paper for merchandise advertisement, high print gloss is demanded because it can excite consumers' curiosity. This presentation will focus on mechanisms of gloss development in nip printings like offset, in terms of coating composition and structure, printing and ink conditions, and printing direction of paper.

THEORY – WHAT IS GLOSS?

Paper gloss is closely related to surface smoothness and commonly regarded as a smoothness index. The reason for this will be described below.

Figure 1 shows a path of light incident on paper surface at 75 º and reflected at 75 º. Specular gloss (or glossiness) is basically related to a ratio of the incident light intensity I_0 to the reflected light intensity I, but more exactly defined as a ratio of the luminous flux reflected by the test surface into a specified aperture at 75 º to that from a standard specularly reflecting surface under the same conditions. To formulate it, specular gloss $G_s(\theta)$ is expressed as:

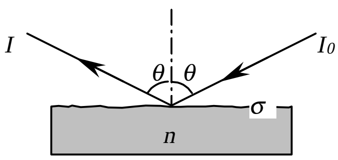

Fig.1 Light path of specular reflection

$$G_s(\theta) = \frac{\rho_v(\theta)}{\rho_0(\theta)} \times 100, \qquad Eq(1)$$

where ρ_v and ρ_0 are the Fresnel equation [1] for the test surface and the standard, respectively, and θ is the incident angle. Following is the exact form of the Fresnel equation, that is, the reflectance for opaque or black glass with a perfectly smooth surface.

$$\rho(\theta,\lambda)=\frac{1}{2}\left[\left(\frac{\cos\theta-\sqrt{n(\lambda)^2-\sin^2\theta}}{\cos\theta+\sqrt{n(\lambda)^2-\sin^2\theta}}\right)^2+\left(\frac{n(\lambda)^2\cos\theta-\sqrt{n(\lambda)^2-\sin^2\theta}}{n(\lambda)^2\cos\theta+\sqrt{n(\lambda)^2-\sin^2\theta}}\right)^2\right], \qquad Eq(2)$$

where n(λ) is refractive index at wavelength λ. For rough surfaces like paper reflectance is also a function of surface roughness as shown below [2].

$$\frac{I}{I_0}=\rho(\theta,\lambda)\exp\left[-\left(\frac{4\pi\sigma\cos\theta}{\lambda}\right)^2\right], \qquad Eq(3)$$

where I and I_0 are intensities of reflected and incident luminous fluxes, respectively and σ is the standard deviation of surface roughness.

The unit of gloss values is defined so that a perfectly smooth surface of glass with a refractive index of 1.540 (1.567 for ISO) is equal to 100 (%). According to *Eq(2)*, this corresponds to 26.01 % in reflectance factor. Therefore, materials with refractive indices higher than 1.540 may have gloss values higher than 100. Differences in the color and the diffuse reflectances of ink films have a negligible effect on measured gloss. For example, at the same roughness, a white surface measures less than one gloss unit higher than the black [3].

Eq(3) means that paper gloss is determined by incident angle of light, incident light wavelength, and refractive index and surface roughness of the paper. Coatings have similar compositions of coating ingredients even for different kinds of coated paper and mineral pigments customarily formulated in coatings have similar refractive indices but titanium oxide. Then, sheet gloss measured under the same optical conditions is dominated by paper surface roughness. Printed surface roughness is supposed to also dominate print gloss because inks have similar compositions of pigments and resins with the refractive indices at close levels.

FACTORS AFFECTING PRINT GLOSS

Print Gloss

Print gloss basically reflects sheet gloss before printing. However, this rule applies to rough paper like uncoated, namely, to the cases where ink coverage is dependent on the extent of surface cavities. For high-grade coated paper to which major attention regarding print gloss is directed, print gloss develops frequently irrespective of sheet gloss. Since 1960’s, it has been stated that print gloss is more normally associated with holdout of ink vehicle on the stock surface, rather than directly with the smoothness of the stock or ink film, because it is vehicle holdout that contributes to the smoothness of the final print and, therefore, to print gloss [4,5]. To keep the mean smoothness of a printed surface, ink vehicle holdout must be made. Otherwise, coatings of less ink vehicle holdout tend to absorb vehicle selectively from ink. But, to the question of why “ink vehicle holdout” or the contrary concept “ink-setting rate” are factors of print gloss, there seems to be two ways of answer. Leveling of an ink film is one answer and menisci development among ink pigment particles is the other. The menisci of vehicle concerned refer to those formed by a drug force of fine coating pores from among ink pigment particles. But, in practice, leveling of an ink film is the primary mechanism.

Figure 2 is a schematic diagram of the interrelationship among various factors affecting print gloss on nip-type printings. This figure implies that ink conditions and printing conditions, as well as paper conditions, develop print gloss in a complicated manner.

In this study, processes of print gloss development were captured by recording “dynamic print gloss” continuously after transferring a sample printed on a universal printability tester, MPT6000,

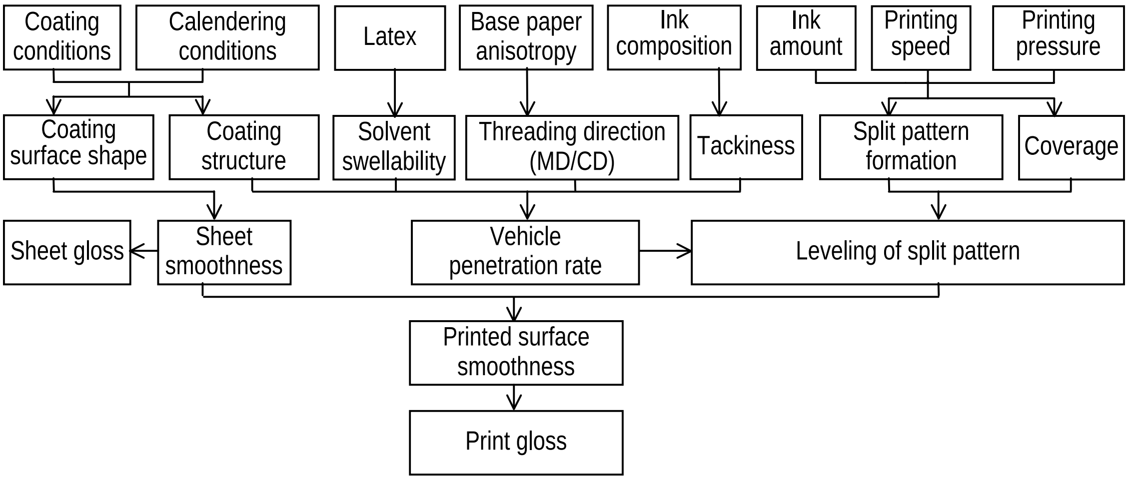

Fig. 2 Interrelationship between factors affecting print gloss of coated paper

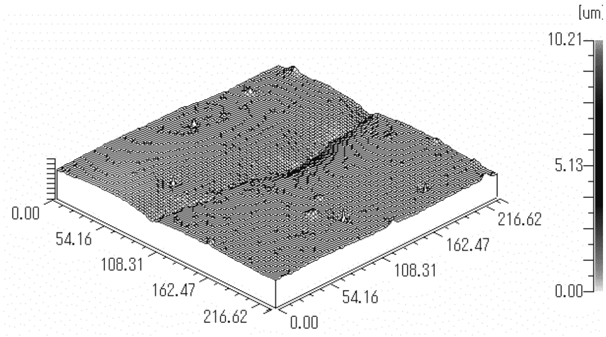

Fig. 3 A groove observed on a printed surface by confocal laser scanning microscope

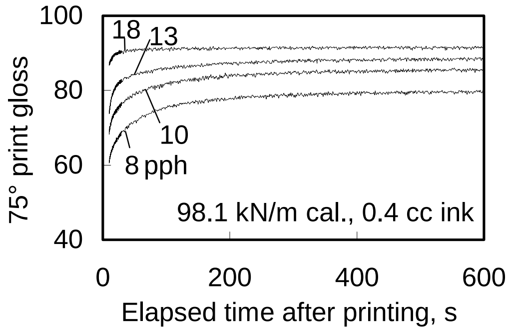

Fig. 4 Dynamic print gloss for coated papers with different amount of latex formulated

KRK, Tokyo Japan, immediately onto a gloss meter, GM-26D, Murakami Color Research Laboratory, Tokyo, Japan, and also by observing changes of small-scale structures of a printed surface immediately after printing with a video-microscope, KH-2200, Hirox, Tokyo, Japan. On passage of a paper sample past a printing nip, the ink film splits with some transferred onto the paper surface and with the rest remaining on the inking roll. This split occurs with the transfer ratio that varied periodically, so a wavy pattern is left on the paper. As the pattern level by a flow of the wet ink film, the dynamic print gloss increases gradually. For uncoated paper and coated paper of imperfect coating coverage, however, collapse of a part of the ink film into large cavities between fibers results in a decrease in print gloss. If the two processes occur subsequently, the print gloss once increases and then decreases [6]. Coated paper at relatively high sheet glosses causes ink film to collapse little. Then, the initial magnitude of the split pattern and the leveling rate of the pattern determine the final print gloss.

Video images (see Fig. 9) which split patterns were recorded with a video microscope as demonstrate that white stripes about 0.5 mm long perpendicular to the printing (threading) direction disappeared with time. This disappearance was found to be consistent with increase in print gloss as evidenced by the result that area of those white stripes calculated by image analysis was correlated well with dynamic print gloss. Note that those white stripes were not mountains, but grooves as shown in Figure 3, confocal laser scanning micrograph (1LM21DW, Lasertec, Yokohama, Japan [7] and their bottoms sometimes lacked in ink with a coated surface exposed, as was observed by scanning electron microscopy. In following chapters, some factors referred-to in Fig. 2 will be discussed.

Influence of Coating Structure

Formulated amount of latex. Ink-setting rate is one of the most important factors affecting print gloss and is determined mostly by pore structure of coatings. The authors presented in the past article [8] that for coated papers containing SB-latex as a binder, the more the formulated latex, the lower the sheet gloss, but the higher the print gloss. As Figure 4 shows, dynamic gloss of coated paper with more latex increased faster immediately after printing and leveled off earlier. This result can be explained by that higher latex content reduced total pore volume and pore diameter, thus leading slow absorption of ink vehicle. Slow absorption of ink vehicle maintains ink film viscosity low and permits the split pattern to level fast. All of the series of experiment were performed under the conditions shown in Tables 1 to 3.

Table 1 Coating color formulation

Ingredient	Amount, pph
Calcium carbonate (UW-90)	100
Starch	3
SB-latex	18, 13, 10 or 8
Dispersant	0.1
NaOH	0.1

Solids 62 %, pH 9

Table 2 Coating conditions

Basis weight of wood-free base	104.7 g/m^2
Coat weight	15 g/m^2
Drying temperature	150 ℃
Calendering pressure	None, 58.9 or 98.1 kN/m
Calendering temperature	50 ℃

Table 3 Standard printing conditions

Test press	Universal printability tester (*KRK*)
Ink grade	Blue for offset sheet-fed
Ink supplied to kneader	0.4 cc
Printing speed	2 m/s
Printing nip pressure	12.3 kN/m
Printed area	200 (printing direction)×40 mm^2

Figure 5 shows surface profiles measured by confocal laser microscope, TCN NT, Leica, Germany, 10 seconds or 2 days after printing. In the sample preparation, the printed samples were soaked in liquid nitrogen to cease the ink flow and dried at –20 °C. This treatment was done according to the common freeze-drying procedure, but, in practice, viscosity of ink vehicle was reduced enough to lose fluidity and volatilized in this treatment. In 10 seconds, the depth of grooves in the split pattern was found to be higher for lower latex content. In 2 days, the depth was much lower for all of the latex contents. However, Fukasawa et al. [9] reported that higher latex content reduced ink-setting rate, but, contrary to the results here, it also reduced print gloss, which indicates that formulated amount of latex could affect other properties of the coating structure in an unknown way.

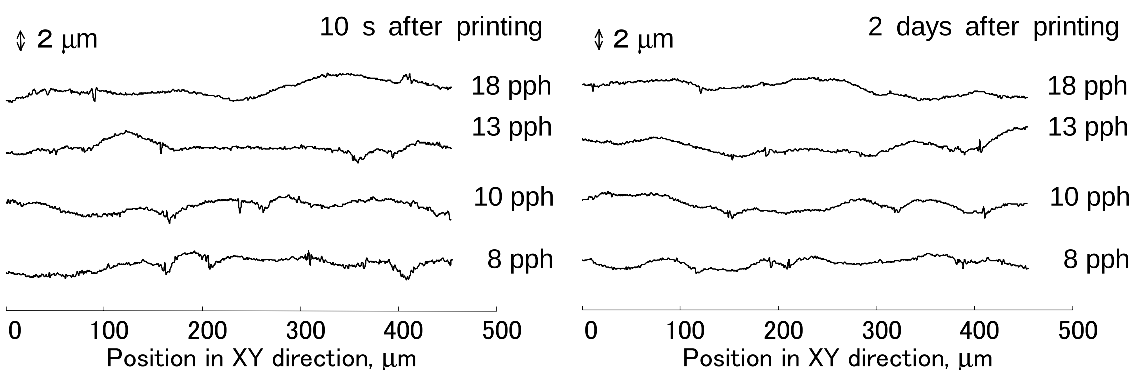

Fig. 5 Surface profiles measured by confocal laser scanning microscope for coated papers with different amount of SB-latex formulated after solid-printing followed by fixing treatment with liquid nitrogen in 10 seconds or 2 days.

Particle size of pigment and pore size of coatings. Ishley et al. reported that the coating that consists of rhombic calcium carbonate with a narrow distribution of a mean diameter of 0.55 µm had a much larger total pore volume than that of ultra fine clay and provided a low print snap, that is, print gloss minus sheet gloss. Donigian and Ishley et al. [10] prepared a series of calcium carbonate pigments with a particle size ranging from 0.19 to 0.45 μm and produced coated papers with them. Smaller average pore diameter at similar total pore volumes caused lower print gloss. The authors inferred that increased capillary draw with fineness of pigment particles as a possible cause. Suzuki et al. [11] reported that, for gloss finished art paper, slow ink-setting rate before lapsing 60 s promoted the leveling of the split pattern and gave higher print gloss. In their previous report, Terao et al. [12] proposed a method for measuring an ink-setting rate. By this method, it was determined from optical densities of smooth film sheets to which unset ink on the destined paper was transferred when several given periods of time elapsed after printing. Area of the transferred ink to the film sheets calculated from the optical densities was found to be proportional to elapsed time after printing and the slope was considered to be the ink-setting rate. Pore structure in the range between 0.13 and 0.15 μm diameter gave the highest correlation with ink-setting rate, thus suggesting that pores in this range selectively absorb ink solvent.

Calendering. Figure 6 shows dynamic print gloss for calendered and uncalendered coated papers. For the uncalendered papers, the maximum of dynamic print gloss was reached 50 to 100 s after printing, and then it decreased gradually. There were large cavities ca 100 μm wide and more than 5 μm deep on uncalendered surfaces The ink film ca 3 μm thick was considered to be not enough to cover them completely and collapse, as is also often the cases with uncoated papers.

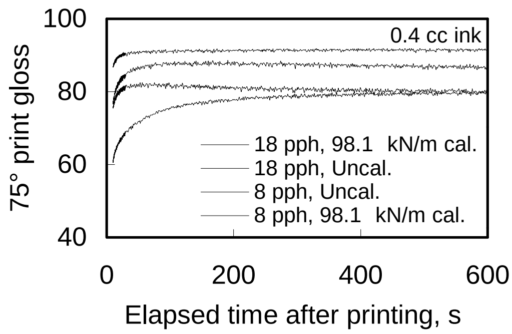

Fig. 6 Dynamic print gloss for calendered and uncalendered coated papers

Chemical factors of coatings. Surface energy of binder also has a great influence on absorption of ink solvent. Gilder et al. [13] reported that the rate of ink-tack build was related to the degree of latex polymer solubility in the ink solvents. Cross-linked polymer (high-gel-content) was less interactive with the offset inks than the linear polymer, but even the linear latex polymer, which were modified to a higher surface energy/polarity level, were less interactive with the ink and resulted in a reduced ink-tack build rate. Kuwamura et al. [14] reported that gel-content and polarity (acrylonitrile content) of SB-latex was closely related to print snap. Furthermore, the contact angle between the latex film in water and the ink solvent, a drop of which flowed in water and attached to the film (two liquid method), had a linear relationship with print snap. The authors considered that it suggested that the water molecule layer adsorbed on the latex polymer in coatings influenced on the ink and coating interaction.

Printing Conditions

Ink amount. Figure 7 shows dynamic gloss of commercially available coated paper with a coat weight of ca 10 g/m^2 per side for different volumes of ink supplied to the ink kneader. The higher the ink volume, the lower the initial rising speed of dynamic gloss. This suggests a larger split pattern for a higher volume of ink, though presumably depending on other conditions as printing speed. For the higher volumes of ink, dynamic gloss continued to increase for longer periods. It is because more unset ink kept fluidity and leveled longer.

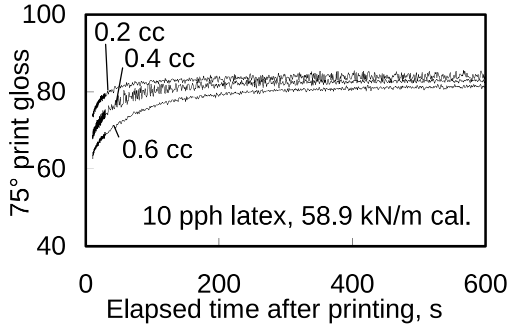

Fig. 7 Dynamic print gloss for different volumes of ink supplied to ink kneader

Printing speed. In comparison among different printing speeds, 2, 4 and 6 m/s, the higher the speed, the lower the print gloss presumably because, for a higher speed, the ink transfer ratio was lower and the initial split pattern was larger as suggested from the lower initial rising speed.

Nip pressure. The higher the printing pressure, the higher the print gloss. Probably, the higher pressure intruded ink more deeply to the surface pores of the coating in the nip, causing the higher ink transfer ratio due to more solidified ink volume.

Glatter et al. [15] analyzed leveling processes theoretically and stated that the fine-scale defects level rapidly, while the large-scale defects level slowly. In their experiment, the video images showed that thick ink films produced large-scale defects that leveled slowly.

Print Gloss Anisotropy Due to Printing Direction

Figure 8 shows dynamic gloss of commercially available coated paper with a coat weight of ca 10 g/m^2 per side printed (threaded) in MD and CD. Figure 9 shows printed surface images taken with the video microscope 2, 10 and 120 s after printing. At 2 s after printing, similar number of white stripes "split pattern" was observed regardless of printing direction. The number decreased with time, indicating the leveling of the split pattern. For MD, the white stripes almost all disappeared at 10 s, while for CD, the white stripes were reduced in width, but hardly reduced in length. Those visual changes corresponded to the measured dynamic print gloss well in that it increased more gradually in CD. Note that all of the glosses were measured in the same direction with that of printing.

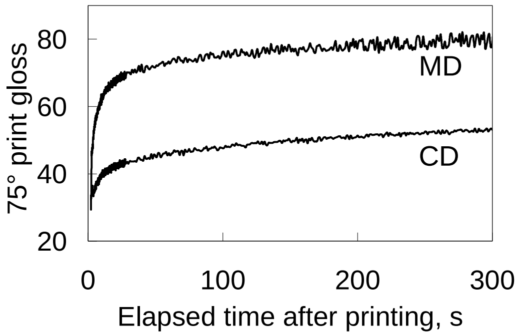

Fig. 8 Dynamic print gloss of commercial coated paper threaded in MD and CD

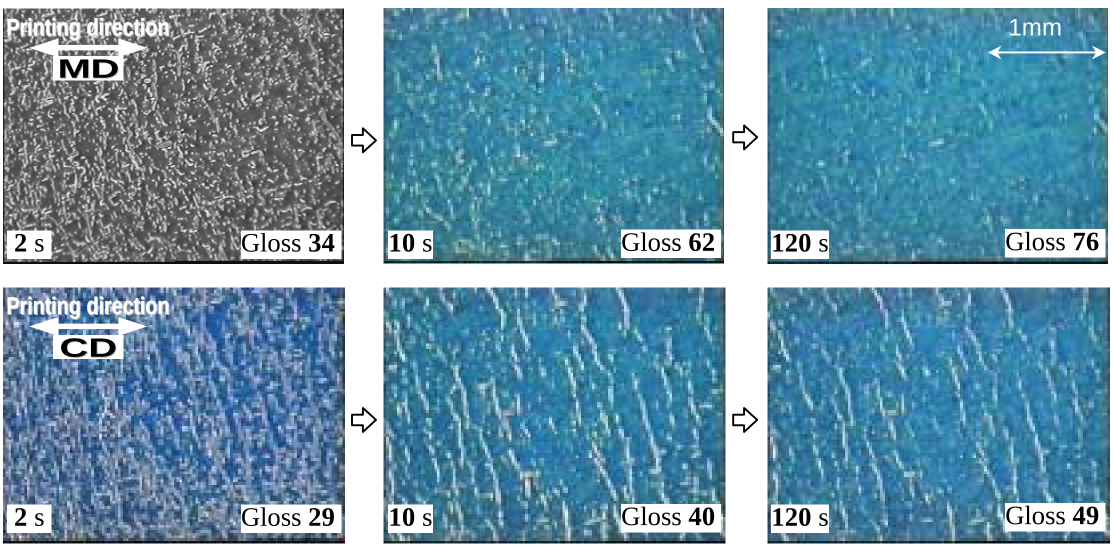

Fig. 9 Video microscope images showing leveling processes of split pattern produced on coated paper. Leveling speed differed between in MD and in CD.

Print gloss anisotropy due to the printing direction seems to stem from paper anisotropy as fiber orientation of the base paper or the coating direction. The difference in dynamic print gloss between MD and CD immediately after impression was modest as observed in the images at 2s, so there should be anisotropy in ink solvent absorption in the leveling process. Looking at other possible reasons, the sheet gloss difference between MD and CD was little. Elastic elongation and shrinkage right in the nip would be negligible because the elastic motion would end well in prior to development of a split pattern. Plastic elongation was found to be too low to take into consideration as a result of measurement.

COCLUSION

In nip printings like offset, print gloss was found to be dependent on many interrelated factors for some cases by continuous print gloss measurements immediately after printing “dynamic print gloss” and by continuous observations with a video microscope. Some of the factors were coating materials. Higher contents of acrylonitrile groups and higher gel contents of latex increased print gloss. Others are as follows; as for coating formulation, higher latex content provided higher print gloss; as for coating structure, a lower pore volume provided higher print gloss and the uncalendered surface turned dynamic print gloss downward halfway; as for printing conditions, a lower speed and a higher nip pressure provided higher print gloss; and as for ink conditions, a higher ink volume on plate provided a lower initial rising speed of dynamic print gloss. How those factors affected print gloss or dynamic print gloss is dependent on secondary factors as ink transfer, ink holdout, magnitude of an initial split pattern and penetration rate of the vehicle controlling the ink viscosity.

Additionally, three-dimensional shape of dried ink films on paper was measured with a confocal laser scanning microscope. It showed that stripes looking white in video images were valleys with gentle slopes on both the sides. It was found using a freeze-drying technique that valleys formed in printing become shallow with time. Printing (threading) direction, MD or CD, also affected print gloss. Anisotropy in ink solvent absorption into a coating somehow due to fiber orientation of the base paper was suggested to cause the print gloss anisotropy.

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