The physical characteristics of inkjet papers and their gloss performance

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Abstract

Gloss has been estimated by the numerical value of the traditional glossmeter, but it is not necessarily in agreement with subjective assessment. The subjective evaluation of gloss is presumed to be related to reflected light intensity and the distribution around the specular direction. We simulate specular reflected light intensity distribution by measuring the surface shapes and optical properties of sample papers. We then conduct a comparative study of the simulation results and the measured distribution.

Introduction

In fields such as offset lithography, photography and inkjet printing, numerous efforts have been made towards the development of technologies that improve gloss to add values on paper products.

Conventionally, gloss ratings are measured by comparing the specular reflectance from a specimen to that from a black glass standard.[1] Image clarity and distinctness of image are other measurement standards by which the gloss reflection of an object onto another surface is appraised.[2] Currently, research into refinements of gloss measurement equipment is advancing, and work is proceeding towards finding ways to eliminate fluctuations induced by measuring equipment, expediting measurement times as well as solving other problems. The gloss fluctuation of inkjet paper samples is measured by using a micro goniophotometer and other instruments capable of determining the optical properties of a surface by the polarized light reflectometry.[3, 4]

The fundamental structure of conventional inkjet paper consists of a plain paper base or a resin-coated (RC) paper base, to which an ink absorbing layer made primarily from water absorbent silica or alumina is coated with binders. While these absorption layers must possess high porosity in order to absorb the ink drop and to retain colorants, such layers are not always applied homogeneously in either the in-plane direction or in the depth direction. Both of these factors (high porosity and non-uniformity of ink absorbing coating) can be presumed to have a significant influence on the distribution of reflected light.

In a normal examination of such coatings, the optical goniophotometric properties of the print gloss are measured in order to evaluate texture and anisotropy. Recently, in the computer graphics field, the bidirectional reflectance distribution function (BRDF) has been utilized to relate optical goniophotometric properties to surface shapes. The Cook-Torrance model in a typical BRDF is based on the microfacet model, which states that a rough surface can be modeled by assuming the existence of a set of oriented mirror-like microfacets.

Recently, high image reproducibility for inkjet printing paper has become possible due to improvements in printer and paper technology. Image gloss is one of the most important factors determining print quality, while gloss uniformity has a predictable influence on a subjective assessment of image quality and media texture. It is expected that gloss non-uniformity correlate with the intensity and distribution of reflected light, surface shape, optical properties, subsurface reflection and other factors. With regards to the cause of the above-mentioned factors, such as the non-uniformity in the gloss of inkjet paper, has not been examined sufficiently.

The principle of a glossmeter is based on the measurement of the specular component of the reflected light. And haze can be objectively evaluated by measuring the diffusely scattered light adjacent to the specular. These evaluations are not necessarily corresponding to the subjective evaluation of gloss. The subjective evaluation of gloss is presumed to be related to reflected light intensity and the distribution around the specular direction.[5]

In this study, we simulate specular reflected light intensity distribution from measured value of the surface shapes and optical properties of various sample paper types. We then conduct a comparative study of the simulation results and the measured distribution.

Optical reflection estimate from Inkjet paper

Basic constitution of inkjet paper:

The coating structures of inkjet paper types range from a simple single-layer coating to more complex multilayered structures, in which separate functions such as colorant retention layers and solvent absorbing layers have been incorporated. Typical structures of inkjet papers are shown in Figure 1. In our reflected light intensity distribution simulation, an inkjet paper sample is assumed to be a composition consisting of an ink absorbing layer coated on a base paper.

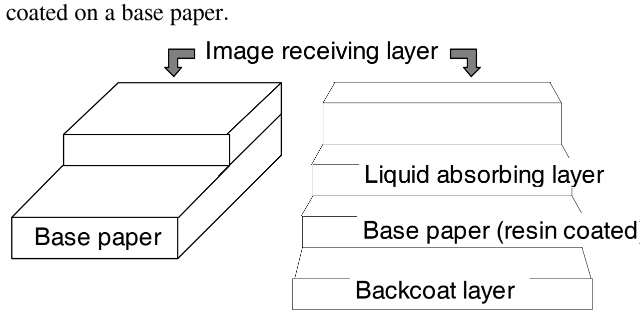

***Figure 1**. Typical structure of inkjet papers*

The ink absorbing layer is regarded as a structure consisting of voids and pigment particles. The existence of voids in the ink absorbing layer results in light scattering, which decreases the color reproducibility of an image. Because the ink absorbing layer must minimize light scattering as much as possible, transparency is necessary.

Microfacet model:

According to Snell's laws, light flux arriving on a perfectly smooth surface is reflected in a single direction, called the specular reflection. Using Fresnel's laws, reflectance is determined by angle of incidence on the surface, refractive index, and polarized light state. When the surface is rough, light scatters in multiple directions with its intensity varying according to the angle of incidence, direction of reflection, and roughness profile.

Torrance and Sparrow proposed a model that assumes a set of the mirror-like microfacets on a rough surface that can be used to predict reflectance. The Cook-Torrance model is based on the Torrance - Sparrow model and is utilized as a computer graphics technique that expresses a genuine glossy-like impression. When roughness is isotropic, the Cook-Torrance model predicts reflectance by assuming the existence of randomly facing rough surfaces that are then represented by a set of mirror-like microfacets. This model presents the scattering phenomenon using the bidirectional reflectance distribution function (BRDF), which sets forth the reflectance of a target as a function of illumination geometry and viewing geometry. The BRDF depends on wavelength, and is determined by the structural and optical properties of the surface. In this case, the BRDF of a surface is calculated according to the following parameters: incident angle, observation angle, surface roughness, and refractive index.

The BRDF is the result of a combination of three factors: reflectance or transmittance factor **F**, the microfacet orientation distribution function **D**, and the geometrical attenuation factor **G**. In this study, the slope distribution obtained by the surface roughness measurement of an inkjet paper sample is used in place of orientation distribution function **D**.[6]

Optical properties of the ink absorbing layer:

Coating colors, which consist of pigments and binders, are applied onto a base sheet. After it dried, the coating forms the ink absorbing layer. The porous structure of the layer is formed during the coating and drying process. Consequently, the coating composition and the production process affect the refractive index of the surface layer. Incident light applied to the ink absorbing layer is reflected, and refracted, in accordance with Fresnel's law. Portions of the light refracted in the ink absorbing layer can be reflected from the surface of the base sheet and ejected from the ink absorbing layer as outgoing light.

In order to estimate reflected light intensity distribution from the factors mentioned above, it is necessary to consider the refractive indices and smoothness of the ink absorbing layer and base paper. The surface profile as the distribution function, and the refractive index of ink absorbing layer, are measured respectively.

Experiment

Paper samples:

All the paper samples used were for inkjet printer and included a photo quality type, a high gloss type, a medium grade type and a silky surface finishing type. Table 1 lists the paper samples used. The coating structures of inkjet paper types range from a simple single-layer coating to more complex multilayered structures.

Table 1: Paper samples

Paper	Grade	Basis weight [g/m^2]	Brightness [%]
A	Photo gloss	245	90
B	Photo gloss	300	96
C	High gloss	190	101
D	Silky finishing	250	92

Surface profile measurement:

The topography of the surface of the papers was measured with a mechanical surface profilometer SE-30D, Kosaka Lab.. A diamond stylus with a radius of 2 μm and a load of 0.7 mN was scanned in the longitudinal direction.

Optical measurement and prediction of reflection:

A goniophotometer (Optec Co., GP-1) was used to obtain the angular distribution of reflected light from the inkjet papers. The geometry for the measurement deals only with zenithal angle of the light source and observation direction. The azimuthal angle is fixed at 180°. The angular distribution of reflected light from the inkjet paper samples was measured at each 10° of incident angle. Parallel light from a halogen lamp was radiated onto the sample, and the reflected light was detected through the lens of a photomultiplier receptor. The signal from the photomultiplier receptor was then imported into a personal computer as digital data.

Reflectance distribution is calculated on the basis of microfacet model. During this process, the measured surface profile is converted into height data. Interpolation between the height data obtained by the quadratic function provides the slope of surface. The above-mentioned slope angle is utilized as the microfacet distribution function. By regarding the pores or cracks of the surface as V grooves, the optical attenuation caused by the surface geometry can then be considered. Based on these factors, reflectance distribution can be estimated using Monte Carlo method.

Results and discussion

Surface profile of inkjet papers:

The results of the measurements conducted on the four types of inkjet paper are shown in Figure 2. It was determined that the use of a relatively large stylus (2 μm) and light loading (0.7 mN) could minimize surface damage. High gloss inkjet paper appears to be manufactured using cast coating methods for based paper and by the multilayer coating method for RC-based paper. It was found that cast coating methods tend to incur defects (such as cracks) on their surfaces.[7] However, when an RC-based paper is used, undulation is generated by substrate waviness. As substrate undulation deteriorates gloss quality, improvements are under investigation.[8] Ruggedness, surface undulation, and minute grooves are shown in Figure 2. These are presumed to be caused by the above-mentioned factors and affect the reflected light intensity distribution of the specular direction.

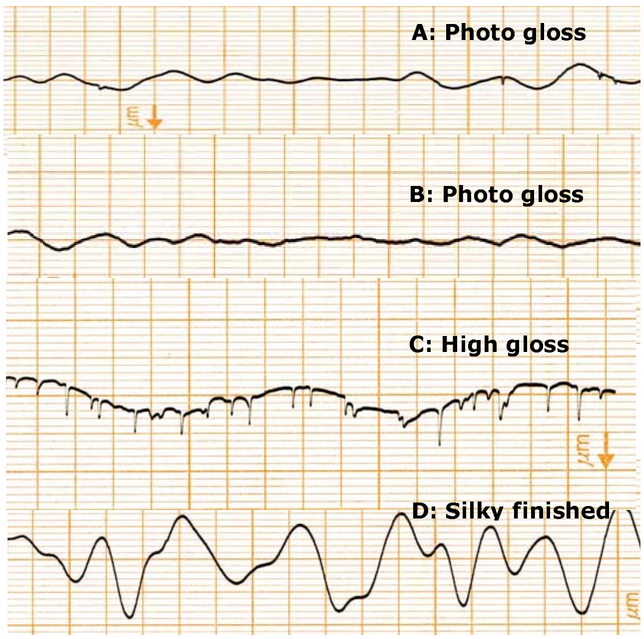

***Figure 2**. Profiles of sample surface*

Refractive index measurement of inkjet papers:

The effective refractive index is generally calculated by a linear combination of the refractive indices of the composition of the coating layer. Therefore, it is necessary to measure the refractive indices of various inkjet papers individually. Ellipsometry is a technology that measures the refractive index from the ratio of reflectance by the use of s-polarized and p-polarized light. This technique is normally applied to smooth surfaces, and has not been applied successfully to paper.[4] By measuring the Brewster angle by p-polarized light, we obtained the refractive index. Thickness of the paper samples generally tended to vary along the machine direction or cross-machine direction due to the influence of the substrate and coating layers, which leads to changes in the slope angles.

We therefore obtained the refractive index by fitting the reflection intensity of s-polarized light to the Fresnel reflectance from 20° to 80°. The result of the refractive index obtained by using the s- and p-polarized light is shown in Figure 3. The results of both refractive indexes showed almost the same value. The refractive index of each inkjet paper sample is shown in table 2 and the pore volume of the ink absorbing layer can be presumed by the obtained refractive index. Assuming that silica and polyvinyl alcohol are used in the ink absorbing layer, the pore volume is estimated at the 25% level.

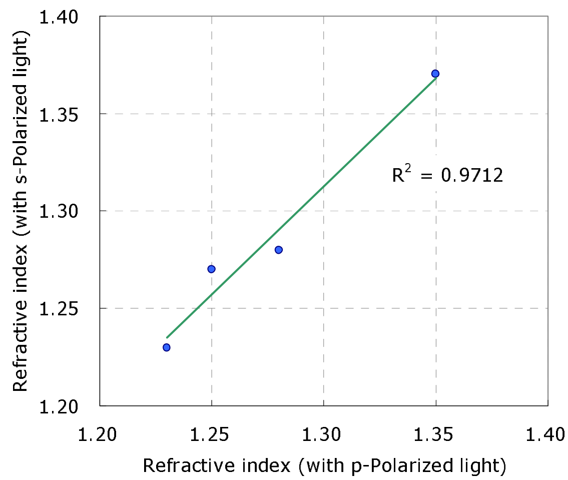

***Figure 3**. Correlation between s-polarized light and p-polarized light measured value of the refractive index*

Table 2: Refractive indices

Paper	Grade	Refractive index
A	Photo gloss	1.30
B	Photo gloss	1.35
C	High gloss	1.29
D	Silky finishing	1.21

Measurement and prediction of reflectance distribution:

The reflected light intensity distribution of the sample inkjet paper, as measured by the goniophotometer, is shown in Figure 4. Measurements were taken at incidence angles of 10°, 20°, 30°, 40°, 50°, 60° and 70°. The reflected light intensity distribution of the sample inkjet printing papers (two photo gloss types, one high gloss type and one silky type) at the incident angle of 70° is shown in Figure 5.

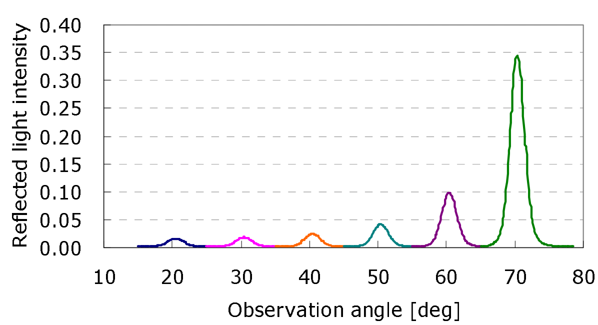

***Figure 4**. Reflective light intensity distribution as a function of the angle of incidence(High gloss type ink jet paper)*

The substrates of the photo gloss, high gloss, and silky type paper samples shown in Figure 2 use RC-based paper. The high gloss type uses the paper substrate, so that it broadens the reflected light intensity distribution. Hereafter, microfacet slope distribution can be presumed to be influenced considerably by the paper structure and the manufacturing process.

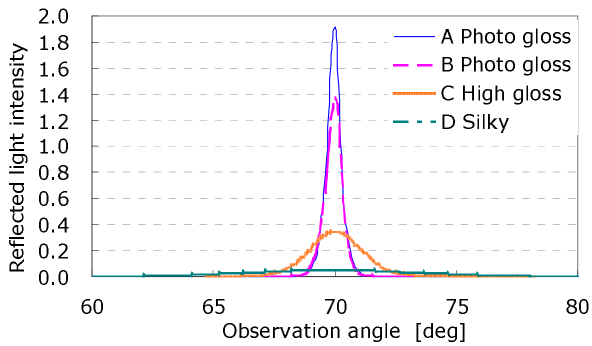

***Figure 5**. Reflected light intensity distribution around the observation angle*

The refractive indices of these inkjet paper sample surfaces are in the range from 1.21 to 1.35. The Fresnel reflectance in this refractive index becomes about 10% at the 70° of incident angle and the refracted light can be reflected on the substrate. The broadening reflected light would afterwards eject toward the specular direction. The simulation result obtained using the measured surface profile data as a distribution function is shown in Figure 6, for example sample A. We obtained the result to which measured reflected light intensity and simulated value were corresponding well as shown in Figure 6.

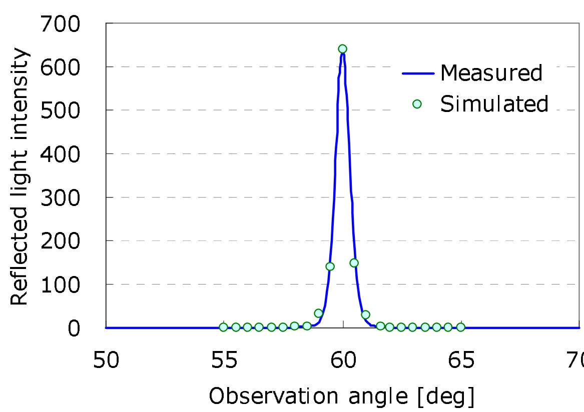

***Figure 6**. Measured and simulated reflected light intensity distribution (Photo gloss type inkjet paper A)*

Conclusion and future work

We selected photo gloss type, high gloss type, and silky type samples from the various inkjet papers on the market, and measured their surface profile and optical properties. The optical properties measured by use of the goniophotometric method were the reflected light intensity distribution around the specular and the refractive index. The results of the measurements showed the refractive index of each sample to be in the range of 1.21 to 1.35. The reflected light intensity distribution was predicted based on measurements of the surface profile and the refractive index. We then simulated the measurements by use of a Monte Carlo method based on the microfacet model. The result of the simulation and the measured reflected light intensity distribution showed a similar profile. To improve accuracy, an examination of the measurement technique and a review of the simulation conditions are required. The content examined by this report is expected to be useful as a technique for determining the influence of a manufacturing condition on the product and on obtaining the optical characteristics of the material. It is believed that the application of this technique to other paper types can be anticipated.

References

[1] J.S. Arney, L. Ye and S. Banach, Interpretation of Gloss Meter Measurements, J. Imaging Sci. Technol. , 50(6), p. 567-571 (2006)
[2] M.-K. Tse and J. C. Briggs, A New Instrument for Distinctness of Image (DOI) Measurements, Proc. Japan Hardcopy '05 (2005)
[3] J.S. Arney and D. Nilosek, Calibration of Gloss Measurements, Proc. IS&T's NIP23, p.391–394 (2006)
[4] N. J. Elton and J. S. Preston, Polarized light reflectometry for studies of paper coating structure Part Ⅰ. Method and instrumentation, Tappi J. , 5(7), p. 8-15 (2006)
[5] M.-K. Tse and J. C. Briggs, Distinctness of Image (DOI) of Inkjet Photo Papers, Proc. IS&T's NIP21, p. (2005)
[6] R. L. Cook and K. E. Torrance, A Reflectance Model for Computer Graphics, ACM Transactions on Graphics, 1(1), P. 7-24 (1982)
[7] T. Enomae, D. Ivutin and A. Isogai, Three-dimensional distribution of ink-jet inks in paper acquired by confocal laser scanning microscope, Proc. 58th APPITA Annual conf. , p. 577-588 (2004).
[8] K. Nagata, et al., Development of High Image Quality Inkjet Printing Paper KASSAI "SHASIN-SHIAGE Pro", FUJIFILM RESEARCH & DEVELOPMENT, No. 56, p.19-24 (2006)

Author Biography

Masaru Kato is a graduate of Chiba University and made researches as a research student in Tokyo Institute of Technology for two years, belonged to Oji Paper Company. After working for Oji Paper Company for many years on assignments involving development of digital printing papers, he joined the Tokyo Polytechnic University in the position of Visiting Scalar in the Color Imaging laboratory.

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