Study about the Evaluation Method of Gloss Unevenness

Kazuhiko Ishizuka^{*2} and Yusuke Kondo

NPi Research Laboratory, Nippon Paper Industries Co., Ltd.^{*1}

Kazuya Takahashi

Hokkaido Mill, Nippon Paper Industries Co., Ltd.

Kazuhiko Ishizuka

Yusuke Kondo

Kazuya Takahashi

Abstract

The system consisting of a line light source, a line scan camera, and a movable stage was used to evaluate the gloss unevenness of coated paperboards. The pattern of gloss obtained from the images was matched with the gloss unevenness obtained by visual test. By frequency analysis of the images, the amplitude at the specific frequency (wavelength was around 6 mm) had strong correlation with the gloss unevenness of visual test. It indicates that this system is available for evaluating gloss unevenness and analyzing its cause. Also, by the result from paper formation measurement, the major cause of gloss unevenness was the uneven formation of base paper. Furthermore, the sheet formation of the surface layer of the coated board had much more influence to the gloss unevenness than that of the middle layer.

Keywords : gloss, unevenness, image analysis, Fourier analysis, frequency analysis

1. INTRODUCTION

The ability of the coated paper to reflect light in the specular direction ; i. e. gloss, significantly affects the visual perception and is sought to be as uniform as possible particularly at high-quality paper and paperboard. Gloss non-uniformity is perceived as macro and micro gloss variation by the visual inspection. Many researches were performed to quantify gloss variation¹⁾⁻⁷⁾. For example, it was reported that paper surface topography determines gloss unevenness. However, they were interested in the micro-gloss non-uniformity of papers which was commonly referred to rough, sandy or scabrous feeling or texture.

We developed an instrument for macro-gloss non-uniformity measurement. The size of each image was several square centimeters and the resolution was in the range of several millimeters. The aim of this research was to quantify the macro-gloss non-uniformity by using our instrument and to elucidate the effects of physical paper properties on it, especially the effects of the sheet formation of each layer.

2. MATERIALS AND METHODS

2.1 Paper Samples

Five commercial high quality paperboards were used in this study. The base paper had two or three layered structures of chemical pulp and the top and bottom surfaces were either single or double coated with pigments. The basis weight was around 400 g/m² and gloss was in the range of 50-70%.

^{*1}5-21-1 Oji, Kita-ku, Tokyo 114-0002, Japan

^{*2}E-mail : kishizuka@nipponpapergroup.com

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Photo. 1 Measuring instrument of gloss unevenness

Fig. 1 Principle of measuring instrument of gloss unevenness

2.2 Gloss Measurement

Micro-gloss was measured using a custom-made microscale gloss setup which consists of two commercial incandescent bulbs (100 Watt) as a light source, a camera for line scanning as a resolution of 2,048 and a movable stage with 230 mm width and 330 mm length. The setup is shown in Photo. 1 and Fig. 1. The light source and the camera are tilted at 45° angle from the vertical axis in order to collect the specular reflection of the light from the sample. The illumination and reflection angle of 45° was selected in order to obtain a similar image of the visual inspection. The camera captured the reflected light in the specular direction over a large area of 230 mm width and 330 mm length at a resolution of $130 \mu\text{m}$. The incident light

intensity was adjusted to achieve the reflected light intensity around 170 ± 10 . The image obtained can be manipulated by LUZEXTM (image analysis software by Nireco) to provide two dimensional Fourier transformation of the center area of $133 \text{ mm} \times 133 \text{ mm}$ consisting of $1,024 \times 1,024$ pixels. An amplitude-wavelength graph is created by plotting amplitude as a vertical axis and wavelength as a horizontal axis. Noise was eliminated by calculating moving average ($N = 10$) to characterize the relationship of the amplitude versus the wavelength of various samples.

2.3 Sheet Formation Measurement

Sheet formation data was obtained using FMT-M^{III}TM (sheet formation tester of Nomura). A CCD camera captured the transmitted light in the area of $120 \text{ mm} \times 180 \text{ mm}$ which consists of 230×320 pixels with a resolution of $500 \mu\text{m}$. The incident light intensity was adjusted to achieve the reflected light intensity around 170 ± 10 . The aperture of the CCD camera was adjusted to get the average intensity of the transmitted light in the range of $35 \pm 2\%$. A multi-layered paper sample was immersed in warm water, delaminated into each layer and dried on a cylinder dryer surface for sheet formation measurement.

3. RESULTS AND DISCUSSION

3.1 Paper Properties

Table 1 shows paper properties of samples. Four experts subjectively rated micro-gloss non-uniformity of samples by visual inspection. Three typical measurements of paper surface properties such as gloss, smoothness and PPS roughness were not sufficient to explain the variance of micro-gloss non-uniformity. Strong correlation did not exist among these measurements and the correlation coefficient R^2 was smaller than 0.5.

3.2 Micro-gloss Non-uniformity

3.2.1 Images of micro-gloss non-uniformity

Fig. 2 shows typical micro-gloss non-uniformity images obtained from the instrument in the area of $140 \text{ mm} \times 110 \text{ mm}$. They looked like the patterns in the visual inspection. Bright areas were of higher gray levels, representing higher local gloss values. On the contrary, dark areas have lower gray levels and represent lower gloss. The similar patterns of bright and dark areas were observed as were perceived by visual inspection. A good correlation seemed to exist between instrument measurements and subjective

Table 1 Paper properties of Samples

Number of Sample	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Basis Weight [g/m^2]	429	431	432	384	379
Thickness [μm]	452	452	459	388	395
Gloss [%]	58	59	58	67	57
Oken Smoothness [sec]	350	490	540	2800	1200
PPS Roughness [μm]	1.9	1.8	1.8	1.1	1.4
Gloss Unevenness [1:poor-5:excellent]	3	3.5	4.5	5	2

(a) Sample 1 (gloss unevenness: 3)

(b) Sample 2 (gloss unevenness: 3.5)

(c) Sample 3 (gloss unevenness: 4.5)

(d) Sample 4 (gloss unevenness: 5)

(e) Sample 5 (gloss unevenness: 2)

Fig.2 Images of gloss unevenness (Size : 140×110 mm)

(a) Sample 1 (gloss unevenness: 3)

(b) Sample 2 (gloss unevenness: 3.5)

(c) Sample 3 (gloss unevenness: 4.5)

(d) Sample 4 (gloss unevenness: 5)

(e) Sample 5 (gloss unevenness: 2)

Fig.3 Frequency analysis of gloss unevenness

tive rating by human eyes.

3.2.2 Fourier transformation of images

Fig. 3 shows the peak amplitude as a function of wavelength. They were obtained by Fourier transformation of micro-gloss non-uniformity images. Fig. 3 (a) reveals the highest peak at the wavelength of 0.8 mm and the small peak at 6 mm. Fig. 3 (b) shows the similar spectrum pattern with Fig. 3 (a). In Fig. 3 (c) the similar spectrum was given but the peak amplitude was low. In Fig. 3 (d), the highest peak was observed at 0.7 mm but there was no peak at 6 mm. The spectrum pattern of Fig. 3 (e) was different from others and two peaks were extracted at 0.7 mm and 5 mm. Fig. 4-1 and Fig. 4-2 show relationship between gloss non-uniformity and the amplitude at the wavelength of 0.8 mm and 6 mm respectively. Fig. 4-2 reveals that micro-gloss non-uniformity was a strong function of the peak amplitude at the wavelength of 6 mm and the correlation coefficient between these two parameters was 0.96.

3.3 Sheet Formation

3.3.1 Measurement of the whole sheet

Fig. 5 shows relationship between the sheet formation index and the peak amplitude at the wavelength of 6 mm of multi-layered paper sheets. Correlation coefficient R^2 was high and found to be 0.745 over the whole range of the sheet formation index from 3.5 to 5.5. Macro-gloss

non-uniformity seemed to be a strong function of the sheet formation. But in the limited lower range of the sheet formation index around at 3.5, the peak amplitude varied significantly even at the small changes of the sheet formation index. It was concluded that sheet formation measurements of the whole sheet were not sufficient to explain the variations of macro-gloss non-uniformity.

3.3.2 Measurement of each layer

Paper samples were separated into several layers including coated surface and bottom layers. Sample 4 was divided into 2 layers while other samples into 3 layers. Fig. 6 shows the sheet formation of each layer. The sheet formation index of the middle layer of sample 2 was lower than that of the middle layer of sample 1. All layers of sample 3 were lower in sheet formation index than sample 1. The surface and bottom layers of sample 3 and 4 had the same sheet formation index. The sheet formation index of all layers of sample 5 was higher than that of sample 1.

Fig. 7-1 and Fig. 7-2 reveal a strong correlation between the peak amplitude at 6 mm wavelength and sheet formation index of the surface layer and the middle layer respectively. Correlation coefficient R^2 was 0.96 for the top layer and 0.74 for the middle layer. These results are comprehensive because the top layer sheet formation has a larger effect on the paper smoothness than the middle layer has. Standard paper measurements such as Tappi

Fig. 4-1 Relationship between amplitude at wavelength 0.8 mm and gloss unevenness

Fig. 4-2 Relationship between amplitude at wavelength 6 mm and gloss unevenness

Fig. 5 Relationship between sheet formation index and gloss unevenness

Fig. 6 Sheet formation index of each layer

Fig.7-1 Relationship between sheet formation index of surface layer and gloss unevenness

paper smoothness, Ohken smoothness and PPS roughness did not correlate well with macro-gloss non-uniformity because they influenced the peak amplitudes at the wavelength of $410\ \mu\text{m}$ and $234\ \mu\text{m}$ ⁸⁾.

4. CONCLUSION

We developed a custom-made setup by using a line light source, a line scan camera and a motorized x-y stage to linearly scan the coating paper samples to quantify the macro-gloss non-uniformity of coated white paperboards, which had not been elucidated by the paper surface topographical data. Images of the macro-gloss non-uniformity were analyzed by Fourier transformation and two characteristic peaks at the wavelengths of 6 mm and 5–6 mm were observed in the spectrum. The peak strength at 6 mm revealed a good correlation with the visual inspection rating of the macro-gloss non-uniformity. This experimental result verified the validity of our instrument. Then we measured the sheet formation of each layer of coated white paperboards, and found a good correlation between the sheet formation of the top layer and the peak strength at the wavelength of 6 mm. It was concluded that the macro-gloss non-uniformity of coated white paperboards strongly depended upon the top layer sheet formation. We

Fig.7-2 Relationship between sheet formation index of sinner layer and gloss unevenness

hope that the instrument helps papermakers in effectively improving macro-gloss non-uniformity.

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