A Study of Sheet Gloss

Nippon A&L INC.
Latex Research Center
Noriko KITAMURA

The tendency to improve the quality of coated paper becomes more and more marked in these years. In connection with this, the demand of increasing sheet gloss of coated paper is also rising.

In our previous paper, we studied sheet gloss and surface roughness of coated paper and found the good relation between sheet gloss and roughness-width larger than pigment size.

In this paper, we focus on the effect of volume change of coating color and constriction of base paper during drying process on surface roughness. To study the properties of coating color and the constrictions of base substance, coating colors are prepared changing in total solids, pigments and water retention agents and are coated on base paper and polyester film.

The result shows that sheet gloss of coated paper depends strongly on volume change of coating color during drying process ; the smaller the volume change of coating color during drying process, the higher the sheet gloss of coated paper. This tendency is same in case of coating on base paper and coating on polyester film. Namely, the coating color, the volume change of which is small during drying process, gives high sheet gloss to the coated paper and such influence is superior to that of the constrictions of base paper which arise from the poor water retention of coating color.

This paper is translated from R&D Report, "SUMITOMO KAGAKU", vol. 2004-I.

Introduction

Coated paper is utilized for most of the color printing that we see on an everyday basis. It is made up of a base paper and a surface coating, which consists primarily of white pigment (such as kaolin (clay) or calcium carbonate) and a binder. Coated paper has outstanding printability, such as whiteness, smoothness and excellent ink acceptance. **Fig. 1** is a scanning electron microscope (SEM) image that shows a cross section of commercially available coated paper. From the image, the coating layers are clearly visible on the surfaces of the base paper.

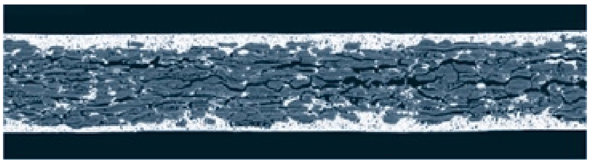

Fig. 1 Cross Section of Coated Paper (SEM Image)

Nippon A & L Inc. manufactures SBR latex, which is used as a binder for coating color (Note: In the paper coating industry, coating material mixtures are called "coating colors."). SBR latex is a synthetic rubber latex composed primarily of styrene (S) and butadiene (B), in the form of an aqueous dispersion in which the rubber constituent is found as a colloid of sub-micron order. In addition to starch, SBR latex is one of the most common coating binders. Acting as more than merely an adhesive, it enhances the strength of a coated layer and also improves its overall structure. Thus, SBR latex can greatly improve both the appearance and the printability of coated paper, which are the most important properties for coated paper. In its quest to develop better SBR latex for even higher quality coated paper, Nippon A & L Inc. has been conducting research into latex and has performed a variety of studies relating to both coated layers and the physical properties of coated paper. In this paper, we shall introduce the results of research that has been focused specifically upon the sheet gloss of coated paper.

Background Information

In recent years, industry trends toward improvements in the quality of coated paper have been accelerating. These trends have resulted in greater expectations for improved sheet gloss for coated paper.

The sheet gloss of coated paper is primarily affected by the shape and size of the pigment particles utilized in the coated layer. It was commonly considered that the sheet gloss of coated paper was directly related to the smoothness of the surface, on a 1-2μm scale, which was approximately the same size as the pigment particles.

However, by using a coated paper model created at our laboratory, we have discovered that the sheet gloss of coated paper is more strongly correlated with the surface roughness (Sm: mean spacing of profile irregularities), which is greater than that of pigment particle size. Thus, we have concluded that having a surface roughness greater than that of pigment particle size is another critical factor that affects the sheet gloss of coated paper [1].

Based on the results of the previous study, we decided to conduct a more detailed study. This study focused specifically upon the factors that affect the abovementioned surface roughness, with resolution greater than the size of the pigment particles, in order to determine how these factors affect sheet gloss. In this experiment we examined two specific factors: volumetric changes in the coating during the drying process (that results in the actual formation of the coated layer); and the deformation of the base paper caused by expansion and contraction (both influenced by water retention in the coating color). In order to analyze these factors, a number of different coating colors were prepared; each varying in total solids content, types of pigments used and water retention agents. Furthermore, in order to compare the effects of base substrate permeability, each coating color was applied to both paper and polyester film.

Experimental Method

1. Base Substrate for Coating

A base paper having a grammage of 61.0 g/m^2 and a polyester film having a grammage of 138.8 g/m^2 were utilized for coating.

2. Coating Color Formation

Table 1 shows the coating color recipes used for this experiment. For pigments, No. 1 kaolin (2μm >90-94%), fine kaolin (2μm>97%), delaminated kaolin (kaolin having a highly lamellar structure: 2μm > 90%) and ground calcium carbonate (2μm>90%). Starch and carboximethyl cellulose (CMC) were utilized as water retention agents for comparison. The latex utilized in the experiment had a particle size of 150nm and a constant quantity of 10 pph was used in each color. A standard solids content of 60% was specified for the coating color. The No. 1 kaolin single pigment color and the ground calcium carbonate single pigment color each utilized 3 different standards for solids content. In addition, the pH of each coating material mixture was adjusted to approximately 9.5 using NaOH.

Table 1 Coating Color Recipe

	A	B	C	D	E	F
No.1 Clay (pph)	100	50				50
Fine Clay (pph)			50			
Delaminated Clay (pph)				50		
GCC (pph)		50	50	50	100	50
Starch (pph)	3	3	3	3	3	
CMC (pph)						0.15
Latex* (pph)	10	10	10	10	10	10
Solid Content (%)	64, 60, 56	60	60	60	68, 64, 60	60

GCC: Ground Calcium Carbonate
Latex: 150nmϕ

3. Coating and Drying Conditions

A sheet fed MLC-100L Laboratory Coater was utilized to apply the coating colors. **Table 2** depicts the coating and drying conditions.

Table 2 Coating, Drying, Calendering

Coating	Coater	MLC-100L
	Coating Speed	10m/min, 1m/min
	Coat Weight	14g/m^2
Drying	Air Temp.	210°C
	Airflow	36m/sec
	Oven Temp.	135°C
	Drying Time	5 sec
Calendering		Non-calendered, 50°C × 20kg/cm, 50°C × 100kg/cm

4. Evaluation and Analysis

(1) Sedimentation Volume of Coating Colors

(Evaluation of Interaction between Pigment and Binder)

The coating colors were first separated and divided into their respective liquid and solids layers using a centrifuge, then the thickness of the solids layer (pigment component) was measured. We have concluded that the thicker the solids layer, the stronger will be either the physical repulsion between the different pigments, or the interaction between the pigments and the binder.

(2) Sheet Gloss

Sheet gloss was measured using a GM-26D glossmeter (manufactured by Murakami Color Research Laboratory; measured at an angle of 75 degrees).

(3) Surface Roughness Sm (Mean Spacing of Profile Irregularities)

The surface roughness Sm was measured using SAS-2010 non-contact surface roughness testing equipment (manufactured by Meishin Koki Co. Ltd.). 400,000 measurement points were taken for each area measured, with one area having a size of 4mm×2mm. A roughness cutoff value of 0.5mm was utilized.

(4) Volumetric Changes in Coating During the Drying Process

Initially, a coating color was applied to the polyester film, with an applicator. After the coating color was allowed to dry at room temperature, the width and thickness of the dried coating film were measured. Subsequently, the cross-sectional area S (mm^2) of the coating film was calculated. The theoretical cross-sectional area S_0 was determined from the thickness and width of the applicator, and then the change in volume was calculated, using the equation shown below. The larger the numeric value, the greater the volumetric change during drying.

$$\text{Change in Volume (\%)} = \{1 - (S/S_0)\} \times 100$$

Results and Discussion

1. Sheet Gloss and Surface Roughness of Commercially Available Coated Paper (Reproduction of the Previous Study)

Prior to our current experiment, the sheet gloss and surface roughness of commercially available coated paper (cast-coated paper, art coated paper, A2 & A3 coated paper and A2 matt paper) were measured, in order to verify the results of the experiment reported in the previous issue. As shown in **Fig. 2**, even in commercially available coated paper comprised of completely different types of pigments, base paper and calendering conditions, there was observed an excellent correlation (correlation coefficient value R^2: 0.97) between the sheet gloss and the surface roughness Sm (roughness resolution ranging from 5-20μm, which is larger than the pigment size, i.e., a roughness with a wavelength of between 10-40μm).

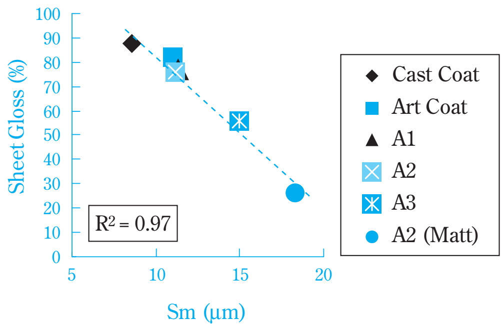

Fig. 2 Surface Roughness (Sm) vs. Sheet Gloss

2. Physical Properties of Coating Colors

Table 3 indicates the Brookfield viscosity (low-shear viscosity), high-shear viscosity, AA-GWR dewatering and sedimentation volume (water retention) for each of the coating colors used in this experiment.

Table 3 Property of Coating Color

	Coating Color	Solid Content (%)	BFV (mPa·s)	HSV (mPa·s)	AA-GWR Dewatering (g/m²)	Sediment Volume (%)
A	No.1 Clay 100pph	64	1790	50	53.4	—
A	↑	60	830	25	68.3	58
A	↑	56	400	15	81.6	—
B	No.1 Clay 50pph	60	520	23	87.7	58
C	Fine Clay 50pph	60	484	19	98.3	59
D	Delaminated Clay 50pph	60	576	30	81.2	60
E	GCC 100pph	68	1646	45	55.2	—
E	↑	64	680	28	78.8	—
E	↑	60	266	18	97.9	55
F	No.1 Clay 50pph (CMC)	60	640	17	115.7	63

BFV: Brookfield Viscosity
HSV: High-shear Viscosity

The dewatering of the coating material was measured by AA-GWR. This measurement represents the quantity of water per unit-hour that migrates from the coating color to the base paper. The dewatering of coating color increases in the order of: A < D < B < C = E < F. This means that the water retention of coating color decreases in the same order. Furthermore, we compared the dewatering characteristics of the two single pigment colors: kaolin and ground calcium carbonate. We found that the No. 1 kaolin (64%) had almost the same dewatering characteristics as the ground calcium carbonate (68%).

We observed differences in the sedimentation volumes of coating colors. When comparing coating colors that had been prepared using different pigments, we discovered that the sedimentation volumes had decreased in the following order: delaminated kaolin ≥ fine kaolin ≥ No. 1 kaolin > ground calcium carbonate. Furthermore, with respect to the coating color that utilized CMC and the coating color that utilized starch, as CMC has a greater sedimentation volume than starch, we concluded that it demonstrates stronger interactions with pigments.

3. Sheet Gloss and Surface Roughness

Table 4 indicates the sheet gloss and surface roughness Sm of each coated paper tested. Coating color "A" (No. 1 kaolin 100pph) demonstrated the highest sheet gloss.

Fig. 3 depicts the relationship between the sheet gloss and the calendering conditions. Color "F" (CMC) demonstrated the best calendering response

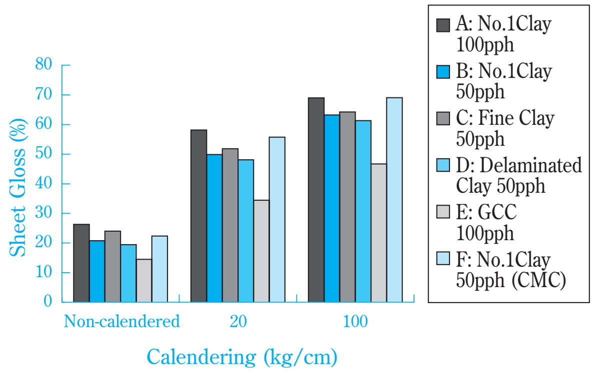

Fig. 3 Relation between Sheet Gloss and Calendering

(improvement in sheet gloss due to calendering treatment), with color "A" (No. 1 kaolin 100pph) coming in as a close second. Color E (ground calcium carbonate 100pph) was the least responsive to calendering. However, although some colors exhibited slight discrepancies in their calendering responses, the general tendency observed was for the sheet gloss to increase with the amount of calendering. Therefore, we can conclude that the paper possesses a preexisting degree of sheet gloss prior to calendering. This same tendency was also observed in the previous study [1]. We detected no differences in the calendaring responses due to the differing pigment types.

When color "F" (CMC), which exhibited less sheet gloss than color "A" (No. 1 kaolin 100 pph) prior to calendering, was subjected to calendering at a line pressure of 100kg/cm, it demonstrated almost the same sheet gloss as the No. 1 kaolin single pigment color.

Fig. 4 and **Fig. 5** depict the relationship between

Table 4 Relation of Sheet Gloss, Surface Roughness

Coating Color		Solid Content (%)	Sheet Gloss (%) Calendering			Surface Roughness Sm (μm) Calendering		
			Non-calendered	20kg/cm	100kg/cm	Non-calendered	20kg/cm	100kg/cm
A	No.1 Clay 100pph	64	28.6	61	71.3	23.7	15.5	13
A	↑	60	26.3	58.2	69	23.6	15	13.4
A	↑	56	24.2	57	67.6	24.8	15.4	13.3
B	No.1 Clay 50pph	60	20.8	49.9	63.2	26.5	15.5	13.5
C	Fine Clay 50pph	60	24	51.8	64.2	24.8	15.8	12.9
D	Delaminated Clay 50pph	60	19.4	48.1	61.3	24	15.3	12.7
E	GCC 100pph	68	20.6	39.9	52	25.8	15.1	13.2
E	↑	64	17.1	37	49.5	27.9	16.7	14.1
E	↑	60	14.5	34.5	46.7	28.1	16.9	14.1
F	No.1 Clay 50pph (CMC)	60	22.3	55.7	69.1	28.7	17.6	14.6

sheet gloss and surface roughness Sm. Fig. 4 indicates the overall correlation for all coated samples, including differences due to calendering conditions. Fig. 5 indicates the relationship between non-calendered papers that are not affected by the calendering response. A strong correlation (R^2 values: 0.89 and 0.82) can be observed in both figures.

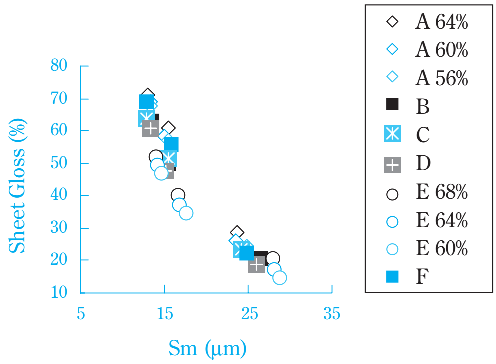

Fig. 4 Surface Roughness (Sm) vs. Sheet Gloss (All Sampeles)

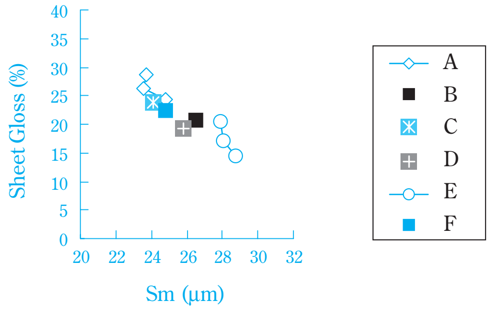

Fig. 5 Surface Roughness (Sm) vs. Sheet Gloss of Non-calendered Sample

4. Volumetric Changes in Coating During the Drying Process

The above results were obtained from the analysis of coating samples that were applied to base paper. However, we thought that the results were greatly affected by the deformation of the base paper itself, due to expansion and contraction during the coating and drying processes. Therefore, we also decided to measure sheet gloss using a different base substrate (a polyester film, which does not expand or contract during coating and drying). The aforementioned equation was used to calculate the changes in volume for the coating colors themselves, before and after the drying process. The results are shown in **Table 5.**

Table 5 Sheet Gloss of Coated Samples (Paper and Film)

	Coating Color	Solid Content (%)	Sheet Gloss of Non-calendered Sample (%)		Volume Change (%)
			Coated Paper	Coated Film	
A	No.1 Clay 100pph	64	28.6	49.6	–
A	↑	60	26.3	48.7	31.8
A	↑	56	24.2	47.3	–
B	No.1 Clay 50pph	60	20.8	33.9	40.1
C	Fine Clay 50pph	60	24.0	42.5	40.4
D	Delaminated Clay 50pph	60	19.4	30.4	39.7
E	GCC 100pph	68	20.6	35.9	–
E	↑	64	17.1	24.8	43.2
E	↑	60	14.5	24.1	–
F	No.1 Clay 50pph (CMC)	60	22.3	41.0	35.8

Fig. 6 depicts the relationship between sheet gloss and volumetric changes in coating during the drying process, for the coated film. The results indicated that the smaller the change in coating volume, the greater the resulting sheet gloss. We have therefore assumed that a smaller change in coating volume during drying will produce a smoother surface on the coating layer, thus resulting in the increased sheet gloss. Furthermore, it appears that coating color "C," which incorporates fine kaolin particles, provides a higher sheet gloss than other coating colors, despite the rather large change in its volume. The cause of this phenomenon has not yet been clarified and is currently under investigation (R^2 values were as follows: 0.71 with C included; and 0.97 without C).

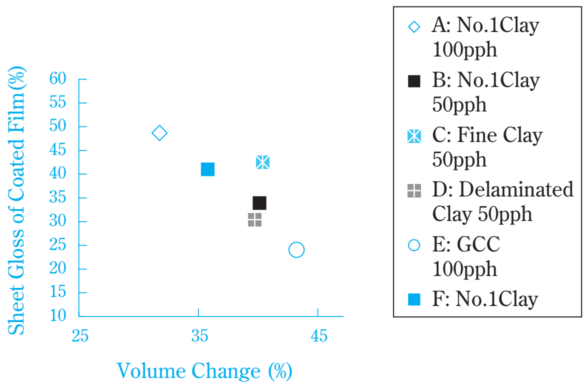

Fig. 6 Volume Change of Coating vs. Sheet Gloss of Coated Film

Fig. 7 depicts the relationship between the sheet gloss of the coated film sample and the coated paper sample. Despite the differences in coating substrates (i.e., one is susceptible to deformation, as it is readily affected by water transferred from the coating color, while the other does not deform), a strong correlation was observed (R^2 value: 0.94).

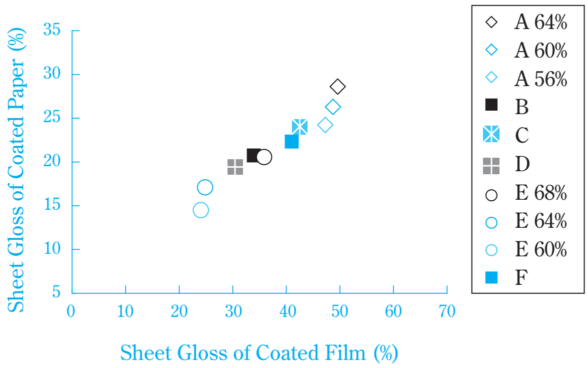

Fig. 7 Sheet Gloss of Coated Film vs. Sheet Gloss of Coated Paper

5. The Effects of Base Paper Expansion and Contraction Due to Water Transfer

We also studied the relationship between the dewatering of coating color (measured using AA-GWR) and sheet gloss, for the No. 1 kaolin single pigment color and the ground calcium carbonate single pigment color. These single pigment colors were prepared in a variety of solids contents. **Fig. 8** depicts the results of this experiment. As compared to the No. 1 kaolin single pigment colors, the ground calcium carbonate single pigment colors demonstrated greater dewatering, i.e., more water transfer to the base paper, thus decreasing the resulting sheet gloss of the coated paper. For each color, as the coating color concentration is increased, the dewaterability of each color decreased, therefore, the sheet gloss of the coated paper increased.

When we compared the dewaterability of the kaolin single pigment colors to that of the calcium carbonate single pigment colors at the same concentration, we observed that the dewaterability of the calcium carbonate single pigment colors was greater than that of the kaolin single pigment colors. However, the dewaterability of the high concentration calcium carbonate single pigment color was less than that of the low concentration kaolin single pigment color. Meanwhile, with respect to sheet gloss, the kaolin single pigment color coated paper demonstrated greater sheet gloss than that of the calcium carbonate single pigment color coated paper.

We have concluded that the reasons that the calcium carbonate single pigment color coated paper demonstrated less sheet gloss than the kaolin single pigment color coated paper include the following: the effects of pigment shape; the coating deformation that occurred during the drying process; as well as the effects from color dewaterability.

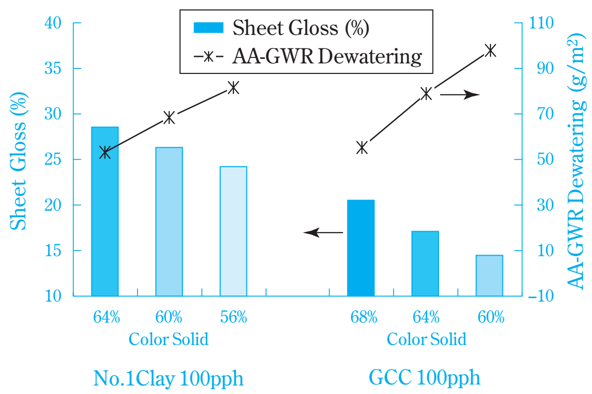

Fig. 8 Sheet Gloss vs. AA-GWR Dewatering

6. Surface Roughness and Volumetric Changes in Coating During the Drying Process

The models shown in **Fig. 9** take into account the roughness of the base paper. These models were presented in order to explain how the volumetric change in coating affects the surface roughness of the coating. As depicted in Fig. 9 (b), a coating that experiences a large change in volume is affected to a greater degree by the underlying roughness of the base paper, thus resulting in a rougher coated layer surface.

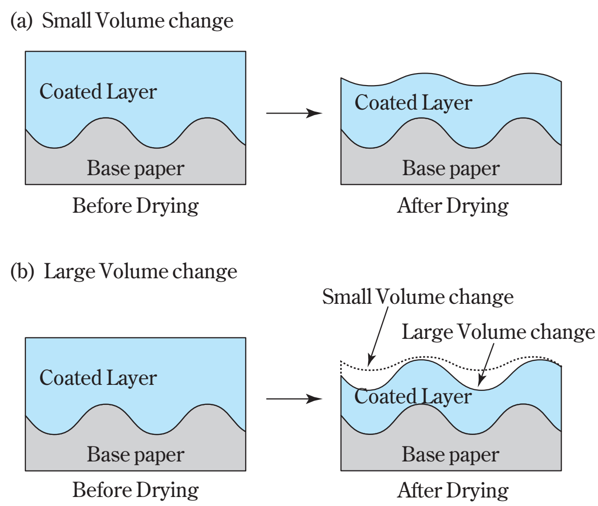

Fig. 9 Volume Change of Coated Layer Before and After Drying

Conclusion

The sheet gloss of coated paper is directly correlated with the surface roughness, at a resolution greater than the size of the pigment particles. This roughness seems to arise from the deformation of the base paper and the volumetric changes in the coating during the drying process.

In this study, we investigated the water retention of the coating color and its effect upon the deformation of the base paper. As a result, the following trend was observed: the lower the water retention of the coating color used in coating, the lower the sheet gloss of the coated paper. This occurs since more dewatering of coating color will occur with decreasing water retention, thus enhancing the deformation of the base paper. On the contrary, a coating color that experiences smaller volumetric changes during the drying process will form a smoother coated layer surface, which demonstrates higher sheet gloss, even though it possesses poor water retention.

Thus, in this experiment, it can be said that the effects of volumetric changes in coating on the sheet gloss of coated paper are greater than the effects of base paper deformation due to water transfer from the coating color.

From these observations, we have concluded that it is possible to produce coated paper possessing outstanding sheet gloss by taking into account the factors described below:

1) Minimize the volumetric changes in coating color that occur due to the drying process, by utilizing pigments that have low packing density or using a binder that interacts strongly with pigments.

2) Minimize deformation of the substrate by utilizing a substrate that possesses high water retention and barrier properties.

Final Words

The sheet gloss of coated paper was previously considered to be affected primarily by the pigment and affected only very slightly by the SBR latex. However, this experiment has demonstrated the fact that the volumetric changes of coating colors during the drying process, which are affected by SBR latex, have a great effect upon the sheet gloss. We, therefore, have discovered a means of enhancing the sheet gloss of coated paper through the use of improved SBR latex. Based upon the knowledge gained from this study, we plan to invest further efforts toward the development of improved SBR latex.

(This paper is a revised version of a paper that was released at the 2003 JAPAN TAPPI annual meeting.)

Reference

1) E.Shiiyama, JAPAN TAPPI, 57(6), 70-76(2003)
2) E.J.Heiser and A.Shand, TAPPI, 56(1), 70(1973)
3) E.J.Heiser and A.Shand, TAPPI, 56(2), 101(1973)
4) E.H.Rossin, PULP & PAPER, 7, 57(1974)
5) B.Alince and P.Lepoutre, TAPPI, 63(5), 49(1980)
6) F.Hoshino and S.Fukaya, TAPPI Advanced Coating Fundamentals (1993)
7) "Coating ; Kamiparupu Seizougizyutu ⑧", JAPAN TAPPI, (1993)
8) L.F.Gate and K.Leaity, TAPPI Coating Conference Proceeding, p.473 (1991)

The literatures 2)-8) are not referred directly in this paper.

PROFILE

Noriko Kitamura

Nippon A&L INC.
Latex Research Center
Research Associate