Effect of the Coating Formulation on the Gloss Properties of Coated Papers

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ABSTRACT

Gloss is one of the optical properties of primary concern to papermakers due to its strong impact on visual perception. In order to improve gloss of coated papers, it is necessary to better understand the relationship governing the behaviour of gloss as a function of surface texture attributes of coated paper. Since pigment represents between 80 to 95 % in weight of any coating colour, pigment characteristics, such as particle size, size distribution, and morphology, play a fundamental role in determining the coating structure. In addition, intensive calendering is often used to achieve a high sheet gloss, but can cause a significant increase in gloss variation (besides to a reduction in bulk). In this study, macro gloss, microgloss and microgloss nonuniformity of laboratory coated paper samples containing seven different delaminated and undelaminated kaolin clays with various particle size distributions were studied as a function of calendering conditions and coat weight. It was found that the average microgloss, given as average gray level, is strongly related to the macro gloss measured using the standard glossmeters. In addition, higher sheet average gloss corresponds to a larger gloss variability at the micro scale. It was also found that by increasing the calendering temperature from 28 to 150°C, the average microgloss and the microgloss nonuniformity increased while the RMS surface heights decreased. For most samples, increasing the calendering temperature resulted in a decrease in surface roughness, $\sigma_h$. A semi-empirical model based on Alexander-Katz and Barrera’s approach of the Kirchhoff theory can be successfully used to identify key surface parameters for gloss and gloss nonuniformity. It showed that the average microgloss of the coated paper is strongly dependent on the surface texture parameter $(L_C/\lambda)/(\sigma_h/\lambda)^2$. In addition, the microgloss variability of these coated papers also exhibited a strong linear correlation with the surface texture parameter $(L_C/\lambda)/(\sigma_h/\lambda)^2$, but the relationship itself was found to be specific to each pigment type.

INTRODUCTION

End use performance of coated papers depends on a proper design of the coating structure. Since pigment represents between 80 to 95 % in weight of any coating formulation, it is clear that pigment attributes, such as particle size, size distribution, and morphology, play an essential role in determining the coating structure and in achieving enhanced optical and printing properties in the final products. It is generally
accepted that gloss is strongly dependent on the roughness of the paper surface and high roughness leads to low average gloss \[1,2\].

Over the years, extensive efforts have been dedicated to investigate the influence of pigments characteristics on average gloss at macro scale and roughness at both macro and micro scales. Morris et al. \[3\] found that delaminated kaolins generated smoother coating surfaces than undelaminated kaolins. These results were attributed to the highly platy shape of the delaminated pigments, which tended to orient parallel to the surface. In addition, the investigators showed that higher 75° Tappi gloss was achieved in papers coated with finer particles of both delaminated and undelaminated kaolins. However, coatings using delaminated kaolins gave the highest gloss for each particle size. Bundy et al. \[4\] ranked correlations between physical and chemical properties of kaolinites and physical properties of kaolinite-starch coatings, and concluded that pigment particle size and shape are most effective in the improvement of average gloss and roughness of the coated sheets. Eklund \[5\] focused on the influence of the pigment shape and particle size on rheological characteristics of coating colours and properties of coated papers. He emphasized that, although finer particles promote higher gloss and lower roughness of coatings, the statement is valid only if the comparisons are made within pigments of the same type. Furthermore, in the case of kaolins the origin of the raw materials matters in the comparisons. English and American (delaminated and undelaminated) kaolins, as well as GCC were used in his work. Lohmander \[6\] showed that pigment particle size appears to affect average gloss more significantly than shape factor, and reported an inverse correlation between the average gloss and surface roughness for uncalendered coated paper. Gate et al. \[1\] showed experimentally that the 75° Tappi gloss has an inverse linear correlation with the root-mean-squared (RMS) surface heights to a power 2 at the microscopic scale. However, this result was obtained for clay-coated polyester films. Pesenti et al. \[2\] examined the effect of pigment shape on the gloss and surface microstructure using polymer films coated with narrowly distributed particles including plate-like clays. The authors reported that clay particles fitted neither the typical 75° Tappi gloss-equivalent spherical diameter (ESD) correlation curve nor the expected 75° Tappi gloss-roughness relationship because of the distinct characteristic shape factors of the particles.

Calendering also modifies coating structure; in fact, coated papers are calendered to improve surface smoothness and increase gloss. Several researchers have examined effects of calendering conditions on the coated paper properties and particularly on average gloss and roughness. Lepoutre and Means \[7\] examined the effect of supercalendering on surface and bulk properties of kaolin coatings applied on polymer films. They confirmed that a joined effect of calendering pressure, “heat”, and number of passes (nips) led to a surface roughness reduction (macro and microroughness) and a gloss increase. According to the authors, while pressure affected macroroughness, heat influenced microroughness. Enomae et al. \[8\] examined the effect of roll temperature, nip load and web speed during the soft calendering of uncoated and coated papers. The researchers reported that temperature caused either a gloss increase or a roughness decrease for all papers studied. Hiorns et al. \[9\] also explored the effect of temperature and nip pressure on coating surface. They found that higher temperatures and lower nip pressures produced a more deformable coating surface with decreased microroughness. In the contrary, lower temperatures and higher nip pressures led to a less deformable coating surface with decreased macroroughness. Moreover,
the authors found a non-linear dependence between either the average gloss or the roughness and the calendering temperature.

Traditionally, assessment of gloss at the same resolution as the surface parameters was not possible because the standard glossmeters only measure average gloss at the macro scale. The development of customized setups to capture, display and assess gloss images of coated paper at higher spatial resolutions allows for a better understanding of gloss related properties at the micro scale [10-15, 22]. It is well known that the rough and anisotropic nature of the substrate brings complications in modeling the specular reflectance of paper surface. Nevertheless, a significant amount of research has been done to understand the gloss properties theoretically. Considering paper as a cluster of micro facets, MacGregor and co-workers [16] reported that microgloss is strongly related to the slope of surface facets obtained from microscopic topography data in the same examined area of the coated paper. Béland and Bennett [17] studied the influence of microroughness of the facets on gloss and gloss uniformity. Beckmann and Spizzichino [18] theorized a model based on Kirchhoff’s electromagnetic wave theory for specular reflection. Also based on the Kirchhoff’s approach, Alexander-Katz and Barrera [19] proposed a generic expression of gloss for polymeric surfaces. Recently, Bernard et al. [15, 20] attempted to explain microgloss non-uniformity of coated papers through Beckmann’s model by assuming paper surface is slightly rough.

However, little work has been done to understand the relationships among gloss, gloss nonuniformity and roughness of coated papers at the micro scale as a function of the pigment properties. Therefore, the aim of the present study is to systematically investigate the impact of different coating formulations and calendering conditions on the relationships between Tappi (macro-) gloss, average microgloss, microgloss nonuniformity, and surface topography of laboratory coated paper samples. In this work, formulations consisting of delaminated, undelaminated, and engineered kaolin clays of different particle size, size distributions and morphology are studied. Also, theoretical models based on Kirchhoff approximation are applied to describe the microgloss and the microgloss nonuniformity of the samples in terms of the surface texture parameters.

METHODS AND MATERIALS

Pigments

Seven commercial kaolin clays with different morphologies, and particle size distributions (PSD) ranging from 48.0% < 2 μm to 98.8% < 2 μm (determined by the Sedigraph™ sedimentation technique) were used in this study (Table I). Three of the kaolins (K4, K7, K9) were received as dry powder and were dispersed in water prior to the coating preparation. Other pigments were received as slurries. As seen from the SEM images in Figure 1, these samples cover a wide range of size distribution.
### Table I. Pigment characteristics.

U: undelaminated, D: delaminated, E: engineered

<table>
<thead>
<tr>
<th>Code</th>
<th>Pigment</th>
<th>Particle Size</th>
<th>Distribution (2)</th>
<th>Morphology</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median (1)</td>
<td>% &lt; 2 μm</td>
<td>Broadness</td>
</tr>
<tr>
<td>K7</td>
<td>Kaolin</td>
<td>0.22 μm</td>
<td>98.0</td>
<td>0.96</td>
</tr>
<tr>
<td>K2S</td>
<td>Kaolin</td>
<td>0.26 μm</td>
<td>98.8</td>
<td>0.65</td>
</tr>
<tr>
<td>K10</td>
<td>Kaolin</td>
<td>0.26 μm</td>
<td>96.0</td>
<td>1.10</td>
</tr>
<tr>
<td>K8</td>
<td>Kaolin</td>
<td>1.03 μm</td>
<td>62.0</td>
<td>2.35</td>
</tr>
<tr>
<td>K4</td>
<td>Kaolin</td>
<td>1.18 μm</td>
<td>66.8</td>
<td>1.33</td>
</tr>
<tr>
<td>K9</td>
<td>Kaolin</td>
<td>1.94 μm</td>
<td>51.0</td>
<td>1.08</td>
</tr>
<tr>
<td>K3N</td>
<td>Kaolin</td>
<td>2.16 μm</td>
<td>48.0</td>
<td>1.24</td>
</tr>
</tbody>
</table>

**Note 1:** Median is defined as $D_{50}$

**Note 2:** Distribution is defined as either:

a) Percentage of the particles are smaller than 2 μm in diameter

b) Broadness or PSD width, defined as $(D_{70}-D_{30})/D_{50}$. 30, 50, and 70 are the percentages of particles smaller than the diameter D.

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**Figure 1.** SEM images of pigments samples (a) K3N and (b) K2S

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**Base Paper**

The coating formulations were applied on a commercial 43-g/m² LWC base paper. The base paper furnish consisted of a mixture of TMP, groundwood, kraft, and recycled pulps.

**Coating Preparation**

A range of different coating colours composed of the pigments described in Table I was prepared. Coating recipes were formulated with 100 pph (parts per hundred) of pigment, and 10 pph of a styrene butadiene (SB) latex as binder (BASF Styronal BN 4606 X, BASF USA). Also, 0.3 pph of a sodium
polyacrylamide salt (BASF Polysalt-PA 30 CL, BASF Germany) was used as dispersant for the powder pigment samples. The pH of the coating suspensions was adjusted to 8.5-9.0 with a 0.5 molar sodium hydroxide solution to assure good dispersion. All suspensions were prepared to 50% solid content by weight. Although the solid content is lower than what is usually applied in the industry, no problem of fiber puffing in the coated samples was found. The observation was confirmed by conducting exploratory trials using 0.3 pph of carboxymethylcellulose (CMC) as thickener. No significant differences in samples of the same formulation with or without the thickener were detected.

**Coating Application, Drying and Conditioning**

A standard procedure using a bench-top laboratory coater (ENDUPAP-Universal Coating Machine Code 275, Testing Machines International, Montreal, Quebec) was followed for preparing the coated samples. The coater speed was kept constant at 3 m/min. Standardized metering rods were used to apply the target coating weights of 15 +/- 2, 23 +/- 2 and 30 +/- 2 g/m² on one side of the base sheet. In addition, the base sheet was coated in the machine direction (MD). Coated samples were dried in the drying chamber of coater for 2 minutes at 200°C and then for an additional 2 minutes in an oven at 105°C. All specimens were conditioned for 24 hrs at 23°C and 50 % relative humidity after coating.

**Calendering of Coated Samples**

A Beloit-Wheeler (Beloit-Wheeler, USA) supercalender was used to finish the coated samples. The calender speed was kept constant (75 m/min). Each sample was calendered at the target temperature, line load, and consecutive passes. The coated sheets were calendered in the machine direction (MD). Thirty three calendering conditions were chosen to be tested. Each calendering condition was defined as a combination of three factors: line load, hard roll temperature and number of passes or nips. These factors were considered within the following levels of observation:

<table>
<thead>
<tr>
<th>Line load:</th>
<th>60, 110, 190, 250, 350 and 500 kN/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard roll temperature:</td>
<td>28, 80, 150 and 165 °C</td>
</tr>
<tr>
<td>Number of passes:</td>
<td>2, 4, 6, 8, 10, 12 and 18 nips</td>
</tr>
</tbody>
</table>

Three coated specimens prepared with a specific pigment were randomly assigned to each of the calendering conditions. *Table II* illustrates nine of the calendering conditions applied on samples with 15 +/- 2 g/m² of coating weight.
Table II. Calendering conditions

<table>
<thead>
<tr>
<th>Code</th>
<th>Line Load (kN/m)</th>
<th>Hard Roll Temperature (°C)</th>
<th>Nips</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>110</td>
<td>28</td>
<td>2</td>
</tr>
<tr>
<td>T2</td>
<td>350</td>
<td>28</td>
<td>2</td>
</tr>
<tr>
<td>T3</td>
<td>110</td>
<td>80</td>
<td>2</td>
</tr>
<tr>
<td>T4</td>
<td>350</td>
<td>80</td>
<td>2</td>
</tr>
<tr>
<td>T5</td>
<td>110</td>
<td>150</td>
<td>2</td>
</tr>
<tr>
<td>T6</td>
<td>350</td>
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<td>2</td>
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<td>T7</td>
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<td>165</td>
<td>4</td>
</tr>
<tr>
<td>T8</td>
<td>500</td>
<td>165</td>
<td>6</td>
</tr>
<tr>
<td>T9</td>
<td>500</td>
<td>165</td>
<td>12</td>
</tr>
</tbody>
</table>

**Tappi Gloss Evaluation**

Gloss at 75° of geometry was determined according to the Tappi T480 om-92 standard. A conventional glossmeter (NOVO-GLOSS™, Rhopoint Instrumentation Ltd., East Sussex, United Kingdom) was used. The plane of illumination of the glossmeter was set parallel to the MD of the sample. The 75-degree average gloss of five randomly selected points in each specimen was reported as the average gloss of the coated samples.

**Microgloss and Microgloss Nonuniformity Assessment**

A custom-made micro-scale gloss measurement setup (Figure 2) was used to obtain the mean microgloss and the microgloss nonuniformity of coated sheets. The resolution of the setup is 16 μm x 16 μm with an effective area of measurement of 1cm². Details of this setup are described elsewhere [13,14]. In the present work, the shutter speed of CCD camera was fixed at 140 msec. Measurements of the mean microgloss and microgloss nonuniformity were done over the same five points selected for the Tappi gloss tests. (Refer to APPENDIX A for definitions of average microgloss and microgloss uniformity).

**Surface Texture Characterization**

A WYKO™ NT-2000 non-contact optical surface profiler system was used to obtain topography data. Based on the interference of light, the instrument reproduces the topography measurement as a 3-D image. Basically the surface profiler combines a microscope with an interferometer. More details of this system are described elsewhere [21]. This kind of instruments is capable to provide highly accurate surface details in many applications, including paper [22]. All the topographic images in this study were obtained by working at a 10.2 magnification, which gives a spatial resolution of 820 nm x 956 nm. The size of each image was 603 μm x 460 μm. A median pass filter was also run to achieve smoothed images.
The profiler measurements were done over three of the five points selected for the microgloss tests. The selection of the three points to be measured was done randomly. The topographic map of each sample obtained from the surface profiler was used to obtain the normalized autocorrelation function and the correlation length \((L_c)\) using a computer program developed in MATLAB® 7.0. The correlation length of the three points of each specimen was obtained by averaging randomly chosen 70 profile lines of the topographic map. The lines were taken along the MD at each point. In turn, the value of the RMS surface heights \((\sigma_h)\) was extracted using the software package supplied with the profiler.

Figure 2. Setup for assessing microgloss and microgloss nonuniformity [13,14]

RESULTS AND DISCUSSION

Characterization of the microgloss and surface topography

Figure 3. Microgloss images acquired with the setup. They correspond to two samples coated with kaolin K10 (0.26 μm) at two different coating weights (underlined), and treated with the same calendering condition. Each of the marked white squares represents a 1-cm² area of microgloss measurement. MD is in the horizontal direction.
Figure 3 shows two examples of images obtained using the microgloss setup. The images consist of visible bright and dark areas. A brighter area has a larger gray level and is associated with a higher local gloss. In the contrary, dark areas have lower gray levels, and hence, represent lower local gloss values. In addition, differences in non-uniformity of gloss are visible in both images with the right sample being less uniform than left sample.

2-D topographic maps of the samples shown in Figure 3 are given in Figure 4. These maps were obtained using the optical surface profiler system. In each image, the color scale represents the height of the surface features.

![Figure 4](image)

**Figure 4.** 2-D topographic maps acquired with the optical surface profiler system. The images correspond to the same samples coated with the kaolin particle described in Figure 3. MD is in the horizontal direction. Image size: 603 μm x 460 μm. Scales in microns.

### Tappi (Macro-) Gloss and Average Microgloss

Figure 5 reveals a strong correlation between the 75-degree Tappi gloss ($G_{75}^\circ$) and the average microgloss ($G_\mu$) obtained for the coated samples examined in this study. Each data point corresponds to the average of three specimens coated with a specific pigment type and calendered under a particular calendering condition. In addition, samples of uncoated base sheet and several commercial coated papers are also included in this plot. There is a strong nonlinear correlation between the average microgloss and the standard gloss for the coated samples with a correlation coefficient of 0.93. This result is in agreement with data available in the literature [13-15, 23]. The reason for the nonlinearity found at 75° illumination geometry may be due to the limitation of the standard glossmeter to discriminate among high gloss samples. This limitation was also pointed out by MacGregor and Johansson [23]. Figure 5 also shows that pigments characteristics greatly influence the gloss values. However, despite the large variations in the pigment size and morphology as well as calendering conditions, all experimental data fall on the same curve. In addition, it can be seen that both the base sheet and the commercial coated papers exhibit a good fit with the shown curve.
Figure 5. Relationship between the average microgloss ($G_\mu$) and the 75-degree Tappi gloss ($G_{75^\circ}$) for all laboratory coated samples prepared in this work. Measurements of the base sheet and commercial coated samples are also included. HG, MWC, and LG represent High Gloss, Medium Coating Weight, and Low Gloss commercial papers respectively.

Effect of Calendering Temperature

Figure 6. Effect of calendering temperature on the RMS surface heights of the laboratory coated samples. Coating weight: 15±2 g/m$^2$. Line load: 110 kN/m. Number of passes: 2. Diamonds: K10. Squares: K2S. Circles: K3N.
RMS surface heights was found to decrease non-linearly with increased calendering temperature (Figure 6). This trend at the micro scale is consistent with the findings reported by Hiorns and co-workers [9], who characterized the smoothness of the coated sheets by Print-Surf technique at pressure of 1000 kPa. The authors attributed the reduction of the surface roughness to three factors, first, the compression effect on the coating layer, which promotes less void volume, smaller pores sizes (less light scattering), and more parallel alignment to the surface of individual clay particles, second, the presence of a more deformable coating layer, and third, the binder coalescence at higher temperatures. According to the authors, little smoothness gain can be achieved by raising the calendering temperature above the coalescence temperature of binder. However, the increase in the average microgloss with the calendering temperature is found to be nearly linear in this study (Figure 7). The impact of calendering temperature on roughness is found to be dependent on the pigment type. For most samples, increasing the calendering temperature from 28 to 150°C resulted in a decrease ($\Delta \sigma_h$) of about 1.5 $\mu$m in the RMS surface heights. However, for coarse delaminated kaolin pigment (K3N), this decrease was only about 0.8 $\mu$m.

![Figure 7. Effect of calendering temperature on the average microgloss of the laboratory coated samples. Coating weight: 15±2 g/m². Line load: 110 kN/m. Number of passes: 2. D: Delaminated particle. U: Undelaminated particle. E: engineered particle.](image)

Figure 8 illustrates the trends in microgloss nonuniformity for the same four pigments considered in the previous figure. As expected, the trends for microgloss nonuniformity is similar to the average microgloss. However, the fine undelaminated kaolin (K2S) showed an unexpected microgloss nonuniformity value at 80°C. The reason for this result is still unknown.
Figure 8. Effect of calendering temperature on the microgloss nonuniformity of the laboratory coated samples. Coating weight: 15±2 g/m². Line load: 110 kN/m. Number of passes: 2. D: Delaminated particle. U: Undelaminated particle. E: engineered particle.

Average Microgloss and Microgloss Nonuniformity

Figure 9 suggests that despite the large scatter in experimental data, a higher average microgloss gives a higher microgloss nonuniformity. In the past, a similar trend was reported for commercial papers [10, 15, 23]. It was found that in the case of the kaolin particles the microgloss nonuniformity of the coated samples is strongly dependent on the size and the morphology of the pigment. Figure 10 shows the relationship between the variance of the microgloss and the average microgloss for two types of kaolins. In the graph, each dot represents an average of three coated specimens calendered with a specific calendering condition. Interestingly, the plot in Figure 10 illustrates the fact that different kaolin-coated samples with the same gloss value, prepared with a similar coating weight, and calendered under identical calendering conditions may exhibit a large difference in microgloss nonuniformity values. Therefore, it is possible to optimize microgloss uniformity of coated papers by selecting appropriate kaolin particles. In addition, the relationship between $G_\mu$ and $\text{Var}(G_\mu)$ for each kaolin is linear. Analysis of experimental data shows a similar trend for other kaolins examined in this study with correlation coefficients $R^2$ ranging from 0.75 to 0.94.
Figure 9. Relationship between the microgloss nonuniformity and the average microgloss for laboratory coated samples. Commercial coated samples as well as the uncoated base sheet samples are also included.

Figure 10. Correlation between the variance of the local microgloss and the average microgloss for kaolins K2S (white diamonds) and K3N (gray diamonds). U: undelaminated, D: delaminated.
Key Surface Texture Parameter Controlling Gloss and Gloss Nonuniformity

It has been shown [24] that a semi-empirical model based on Alexander-Katz and Barrera’s approximation of the Kirchhoff theory [19] for rough exponentially distributed surfaces can be successfully applied to describe the relationship between gloss and surface texture of the coated paper samples. The model identified that key surface texture properties controlling gloss are RMS surface heights ($\sigma_h$) and correlation length ($L_c$) based on the surface topography. A new surface texture parameter is defined using the ratio $(L_c/\lambda)/(\sigma_h/\lambda)^2$, with $\lambda$ as the wavelength of the incident light. Figure 11 illustrates a strong correlation between the average microgloss and the surface texture parameter $(L_c/\lambda)/(\sigma_h/\lambda)^2$. The correlation coefficient is 0.84.

Despite the wide range of pigment size and morphology as well as the calendering conditions, Figure 11 shows that the average microgloss of the samples is a linear function of $(L_c/\lambda)/(\sigma_h/\lambda)^2$.0.23. However, the reason associated with the origin of the exponent 0.23 is not known. It is interesting to note that four (4) different grades of commercial coated samples ranging from low to high gloss also fall on the same regression line. It implies that for a given incident light of wavelength ($\lambda$), the average microgloss ($G_\mu$) is mostly dependent on the surface geometry.

\[ G_\mu = 355 \cdot f(\sigma_h, L_c)^{0.23} \]
\[ f(\sigma_h, L_c) = (L_c/\lambda)/(\sigma_h/\lambda)^2 \]

Figure 11. Average microgloss and the surface texture parameter $(L_c/\lambda)/(\sigma_h/\lambda)^2$.

Figure 12 is the log-log plot of the variance of the microgloss versus parameter $(L_c/\lambda)/(\sigma_h/\lambda)^2$ for the kaolins K3N, K4 and K7 used in this study. A strong linear correlation was found for each pigment type, which agrees with the findings discussed in [24]. In Figure 12, the higher the slope of the line, the more sensitive the gloss variability is to the changes in the surface texture of paper.
Figure 12. Relationship between the variation of the average microgloss measured with the setup and the ratio \((L_c/\lambda)/(\sigma_h/\lambda)^2\) for kaolins K3N, K4 and K7. Rest of pigments in this study exhibit similar behavior. \(R^2\) ranges from 0.70 to 0.90.

CONCLUSIONS

Macro gloss, microgloss and microgloss nonuniformity of laboratory coated paper samples containing seven different delaminated and undelaminated kaolin clays with various particle size distributions were studied as a function of calendering conditions and coat weight. It was found that the average microgloss, given as average gray level, is strongly related to the macro gloss measured using the standard glossmeters. In addition, higher sheet average gloss corresponds to a larger gloss variability at the micro scale. In the case of kaolins, this relationship is highly dependent on the pigment attributes; therefore, the selection of pigment is an important factor in order to achieve the desired gloss and gloss variability. It was also found that by increasing the calendering temperature from 28 to 150°C, the average microgloss and the microgloss nonuniformity increased while the RMS surface heights decreased. For most samples, increasing the calendering temperature resulted in a decrease in surface roughness, \(\sigma_h\). A semi-empirical model based on Alexander-Katz and Barrera’s approach of the Kirchhoff theory can be successfully used to identify key surface parameters for gloss and gloss nonuniformity. It showed that the average microgloss of the coated paper is strongly dependent on the surface texture parameter \((L_c/\lambda)/(\sigma_h/\lambda)^2\). In addition, the microgloss variability of these coated papers also exhibited a strong linear correlation with the surface texture parameter \((L_c/\lambda)/(\sigma_h/\lambda)^2\), but the relationship itself was found to be specific to each pigment type.
ACKNOWLEDGMENTS

The authors gratefully acknowledge the financial support of Surface Science Research Consortium II members at the Pulp and Paper Centre, University of Toronto, and Natural Sciences and Engineering Research Council of Canada (NSERC). Also the authors wish to thank Dr. Nicolas Dechamps, a post doctoral fellow at the Pulp and Paper Centre for his helpful comments and his help with mathematical programs. Finally, the authors appreciate the supply of pigments and chemicals by Huber, Imerys, and BASF.

REFERENCES


APPENDIX A

In this study, the following definitions are used:

**Average Microgloss**

The arithmetic average of the gray level value for all pixels \((i,j)\) in the measured area captured by the microgloss setup (Figure A)

\[
G_\mu = \frac{\sum G_\mu(i, j)}{N} \tag{A.1}
\]

where:
- \(G_\mu\) = average microgloss
- \(G_\mu(i,j)\) = gray level for the element in the \(i^{\text{th}}\) row and \(j^{\text{th}}\) column in Figure A
- \(N\) = total number of pixels \((i,j)\) in Figure A

**Microgloss Nonuniformity**

The standard deviation of the gray level value of all pixels in the measurement area that is captured using the microgloss setup (Figure A).

\[
\sigma_{G_\mu} = \sqrt{Var(G_\mu(i, j))} \tag{A.2}
\]

where: \(\sigma_{G_\mu}\) = microgloss nonuniformity