

Relationship between gloss and surface texture of coated papers

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ABSTRACT: Gloss strongly affects visual perception and print quality of coated papers. In this study, we investigated standard TAPPI gloss and microscale gloss of several commercial and laboratory-made coated samples. The laboratory coated samples contained seven different kaolin clays and four ground calcium carbonates with a wide range of pigment morphology, particle size, and particle size distributions. The samples were calendered at various conditions. We found that coated paper samples were optically rough surfaces with Rayleigh parameter much larger than 1. A semi-empirical approach using the root-mean-square roughness, σ_h , and correlation length of surface heights, L_c , showed that gloss of coated samples is proportional to $(L_c/\sigma_h^2)^n$. The exponent n was found to depend on the angle of illumination. For the TAPPI 20°, TAPPI 75°, and 60° standard gloss, as well as average microgloss, n was 0.41, 0.31, 0.52, and 0.23, respectively. Despite large variations in the pigment size, morphology, and calendering conditions, all data points closely followed the same regression line, suggesting that gloss is predominantly governed by the surface texture of paper.

Application: The fundamental understanding of the parameters defining paper surface texture and their effect on gloss can help papermakers optimize the optical response of coated papers.

For papermakers, gloss is one of the most important optical properties because it strongly affects visual perception and print quality. Coated papers with high gloss are generally considered to have a better print quality. Even though gloss at the macro scale has been investigated extensively over the years [1-3], little has been reported on gloss at the submillimeter scale. However, as papermakers are targeting higher value-added products, better understanding of the gloss properties of coated papers (especially at the micro scale) and the relation between gloss and the surface texture of the final product becomes increasingly important.

The effect of surface texture on gloss has been investigated intensively using electromagnetic theories for the diffuse reflection of light from random surfaces. Since Chinmayanandam [4] first presented an algebraic expression describing the ratio of the specular reflection of matte (rough) and perfectly smooth surfaces as a function of the angle and the wavelength of the incident light, several mathematical models have been proposed to explain light scattering from rough surfaces [5-12]. These models are mostly based on the scalar Kirchhoff's approximation, such as the Beckmann model [6] for random rough surfaces. This approach explains the intensity of reflected light in the specular direction in terms of a coherent and a diffusive component of the scattered light field. The relative significance of the coherent and incoherent light scattering components depends on the incidence angle of light, θ_i , and surface roughness as characterized by the dimensionless Rayleigh parameter, g_s [10]:

$$g_s = \frac{16\pi^2}{\lambda^2} \sigma_h^2 \cos^2 \theta_i \quad (1)$$

where λ is the wavelength of the incident light, and σ_h is the surface roughness expressed as root-mean-square (RMS) roughness of surface height. The latter parameter is the standard deviation of local height, z_i , with respect to the mean surface measured at discrete and equally separated points on the surface of the sample [13]:

$$\sigma_h = \left(\frac{1}{P} \cdot \sum_{i=1}^P z_i^2 \right)^{1/2} \quad (2)$$

Application of the Beckmann model requires knowledge of the normalized autocorrelation function (hereafter denoted as ACF). Mathematically, the ACF of a continuous real function $z(x)$ is defined as [14]:

$$B(\tau) = \lim_{L \rightarrow \infty} \left[\frac{1}{2L} \cdot \int_{-L}^L z(x) \cdot z(x + \tau) \cdot dx \right] \quad (3)$$

where $B(\tau)$ is the autocorrelation function, L is the profile length, τ is the lag length (lateral shifting separation between two exactly same surface features along a line), x is the location along the surface profile, and $z(x)$ represents the local surface height at positions x . However, $B(\tau)$ is often normalized by the variance of the local surface height:

$$C(\tau) = \frac{B(\tau)}{\sigma_h^2} \quad (4)$$

where $C(\tau)$ is the normalized autocorrelation function. Based on this equation, the normalized ACF is equal to 1 for a lag length of $\tau = 0$.

A key parameter that characterizes the autocorrelation function is the correlation length, L_c . This parameter is defined as the characteristic length or “lag” at which the normalized ACF function is equal to e^{-1} . Physically, the correlation length describes the statistical size of surface features [15], such as bumps on the paper surface. Extensive discussion on the ACF and the correlation length can be found elsewhere [13,16].

Assuming a Gaussian ACF, Beckmann and Spizzichino [6] proposed the following model for the specular reflection from a smooth surface ($g_s < 1$):

$$G_{\theta_i} = G_{\theta_i}^{\circ} \exp \left[- \left(\frac{4 \pi \sigma_h \cos \theta_i}{\lambda} \right)^2 \right] \quad (5)$$

where G_{θ_i} is the gloss for the light incident angle θ_i , and $G_{\theta_i}^{\circ}$ is the gloss at the incidence angle θ_i for a perfectly conducting smooth surface.

Beckmann's model, represented by Eq. (5), has been applied by several researchers to describe the gloss of coated samples [17-19]. Working with coated polymer films as substrates, Gate *et al.* [17] demonstrated empirically that TAPPI 75° gloss has an inverse linear correlation with the squared RMS roughness at the microscopic scale. Lee [18] and Pesenti *et al.* [19] also found an inverse relationship between surface roughness and TAPPI 75° gloss of coated films. Although these findings were consistent with the prediction of Beckmann's model, the experimental data used in these studies were limited to smooth coatings with roughness values smaller than the wavelength of the light ($g_s < 1$). Recently, using the phase-perturbation approach, Simonsen *et al.* [12] derived an analytic expression for predicting gloss of random rough surfaces as a function of the RMS roughness and a power spectrum dependent on the correlation length. They reported a good agreement between the predicted gloss values and the results obtained from Monte Carlo simulations for surfaces with optical roughness values g_s smaller than one.

For very rough surfaces ($g_s \gg 1$), the incoherent contribution of the scattered reflected power prevails. For this situation, Alexander-Katz and Barrera [10] proposed the following generic expression:

$$G_{\theta_i} \propto \left[\frac{L_c / \lambda}{(\sigma_h / \lambda)^a} \right]^2 \quad (6)$$

where a is equal to 1 for a Gaussian ACF and equal to 2 for an exponential ACF. Equation (6) relates the specular reflection of light to easily measurable surface parameters. Alexander-Katz and Barrera showed that the incoherent component of the scattered light had significant contribution to the gloss value of rough surfaces.

In the case of paper, researchers generally agreed that surface topography plays a major role in light scattering and gloss properties [18,20,21]. However, the rough and anisotropic nature of paper coatings introduces additional challenges

in the modeling of the specular reflectance of light. Lee [18] discussed the influence of surface macro- and micro-roughness on gloss. He suggested that improvement in the gloss of paper was due to the reduction of macro-roughness.

Oittinen [20] proposed a model for the specular reflectance based on the independent effects of the RMS roughness and the distribution of roughness slopes. He also distinguished micro-roughness (determined by coating components characteristics, such as pigment particle size and size distribution) and macro-roughness (related to the base sheet structure) as the main components of the total surface roughness.

Other researchers [22, 23] studied paper gloss by assuming paper to be a cluster of microfacets. Although this model is able to explain light scattering at the surface of paper, the identification of the microfacets is not trivial and the model parameters are hard to interpret. Lettieri *et al.* [24] examined the roughness of glossy coated papers using an angle-resolved light scattering (ARLS) technique. Assuming a Gaussian distribution for surface heights and a quasi exponential ACF, Lettieri and colleagues [24] proposed a description of the diffuse reflection of light from coated papers using Beckmann's model. More recently, Bernard *et al.* [25] attempted to explain microgloss of commercial coated papers based on the Beckmann model. They confirmed that the relationship between the microgloss and the RMS roughness deviated from the predictions of Beckmann's model. Reported application of electromagnetic theories for predicting gloss of coated papers has been limited to surfaces that are much smoother than typical commercial papers. The aim of this work was to examine the application of Kirchhoff's approximation for rough surfaces to coated papers and to identify key surface texture parameters that govern the gloss of coated papers over a wide range of roughness values.

MATERIALS AND METHODS

Paper samples

We used seven commercial kaolin clays and four ground calcium carbonates (GCC) to prepare laboratory coated samples. Kaolin clays included delaminated, undelaminated, and engineered pigments. **Table I** lists particle sizes (PS) and size distributions (PSD) of the pigments used in this study. Coating recipes were formulated with 100 parts per hundred (pph) of pigment and 10 pph of a styrene butadiene (SB) latex as binder (BASF Styronal® BN 4606 X, BASF USA). We used 0.3 pph of a sodium polyacrylamide salt (BASF Polysalt® PA 30 CL, BASF Germany) 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.

The model coatings were applied on a commercial 43 g/m² lightweight coated base paper. The base paper furnish consisted of a mixture of thermomechanical pulp, groundwood, kraft, and recycled pulps. We followed a standard procedure using a bench-top laboratory coater (ENDUPAP-Universal

Code	Pigment	Median Size (μm)	% < 2	Broadness ⁽¹⁾	Morphology ⁽²⁾
K7	Kaolin	0.22	98.0	0.96	U
K2S	Kaolin	0.26	98.8	0.65	U
K10	Kaolin	0.26	96.0	1.10	E
K8	Kaolin	1.03	62.0	2.35	U
K4	Kaolin	1.18	66.8	1.33	D
K9	Kaolin	1.94	51.0	1.08	D
K3N	Kaolin	2.16	48.0	1.24	D
GCC1	GCC	3.49	34.4	0.97	-
GCC2	GCC	1.53	62.7	1.54	-
GCC3	GCC	0.74	90.3	1.20	-
GCC4	GCC	0.77	93.2	0.89	-

Note 1: Broadness is defined as $(D_{70}-D_{30})/D_{50}$.

Note 2: U: undelaminated, D: delaminated, E: engineered

I. Pigment characteristics used in this study. Data as provided by suppliers.

Coating Machine Code 275, Testing Machines International, Montreal, Quebec, Canada) for preparing the coated samples. The coater speed was kept constant at 3 m/min. Standardized wire-wound metering rods were used to apply the target coating weights of 15, 23, and 30 g/m² in the machine direction (MD) on one side of the base sheet. The selected types of rod had narrow and rounded threads. They created coatings that were free of lines and other artifacts as examined by naked eye and by optical surface profiler. The coated samples were dried in the drying chamber of the coater for 2 min at 200°C and then for another 2 min in an oven at 105°C. All specimens were conditioned for 24 h at 23°C and 50% relative humidity after coating.

The coated samples were finished using a Beloit-Wheeler (Beloit-Wheeler, USA) supercalender. The calender speed was kept constant (75 m/min). Each sample was calendered in the MD at a specific calendering condition defined as a combination of three factors: line load, steel roll temperature, and number of passes or nips. **Table II** lists the rang-

Line Load (kN/m)	60, 110, 190, 250, 350, and 500
Hard Roll Temperature	28°C, 80°C, 150°C, and 165°C
Number of Nips	2, 4, 6, 8, 10, 12, and 18

II. Calendering conditions.

es for these factors. For a specific pigment and calendering condition, three coated specimens were prepared.

In addition to laboratory coated papers, four different grades of commercially produced coated papers were included in this study. According to their TAPPI 75° gloss value, these samples were categorized as low gloss, medium gloss, and high gloss.

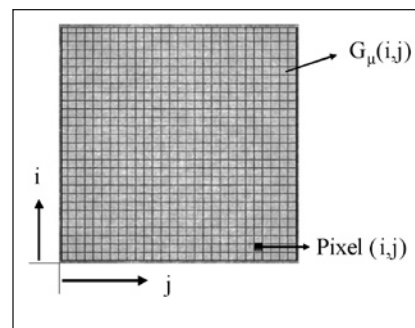
Gloss measurement

Microgloss was measured using a custom made microscale gloss set up. Details of this setup are described elsewhere [26]. Each sample was illuminated using a collimated light source (Thermo-Oriel) at 23° angle. A digital camera (Kodak Megaplug) captured the reflected light in the specular direction over an area of 1 cm² at a resolution of 16 μm . Average microgloss, G_μ , was calculated as the arithmetic average of the gray level value of all the pixels in the image area captured by the microgloss setup [26].

$$G_\mu = \frac{\sum G_\mu(i, j)}{N} \quad (7)$$

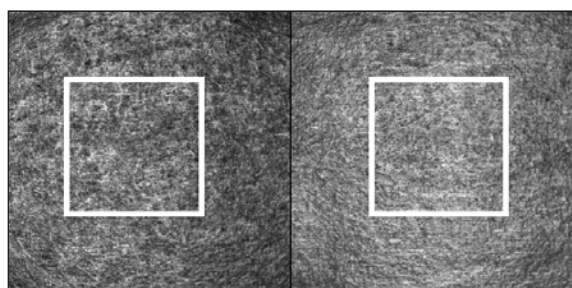
where G_μ is the average microgloss, $G_\mu(i, j)$ is the gray level for the pixel located in the i^{th} row and j^{th} column, and N is the total number of pixels (**Fig. 1**).

Figure 2 shows two examples of



1. Schematic representation of the image captured by the microgloss setup [26]. The overlapped grid illustrates pixels in the digitized image.

the obtained microgloss images. A brighter area corresponds to a higher gloss. The average value of microgloss of each image is assessed for an area of 1 cm² represented by the marked white square. In turn, gloss at 20°, 60°, and 75° (i.e., G_{20° , G_{60° , and G_{75°) was measured in conformity with the TAPPI T 653 pm-90 [27], ASTM D523-89 [28], and TAPPI T 480 om-92 [29] standard methods, respectively, using a conventional glossmeter (NOVO-GLOSS™, Rhopoint Instrumentation Ltd., East Sussex, United Kingdom). The plane of illu-



2. Light reflection images of the coated samples: with 15 g/m² (left) and 23 g/m² (right) coating weights (pigment: K10; calendering condition: 110 kN/m, 80°C, 2 nips). White squares mark the 1 cm² areas used for microgloss analysis.

mination of the glossmeter was set parallel to the machine direction of the sample. The average gloss of five randomly selected points in each specimen was reported. The average microgloss was obtained over the same five points selected for the gloss tests in each specimen.

Surface texture characterization

We used a WYKO™ NT-2000 noncontact optical surface profiler system to obtain two-dimensional topographic maps of each sample (Fig. 3) and the value of RMS roughness. All the images captured with the surface profiler in this study were obtained by working at a 10.2 magnification, which corresponds to a spatial resolution of 820 nm × 956 nm. The size of each image was 603 μm × 460 μm. We used a median pass filter to smooth the images and reduce noise. The scale shown in Fig. 3 represents the height in microns of the surface features with respect to an average plane. The topography measurements were done at three of the five points selected for the microgloss tests. The RMS roughness was calculated based on Eq. (2). The roughness measured by this method correlates well with the results obtained using air-leak and stylus profiler techniques [30, 31].

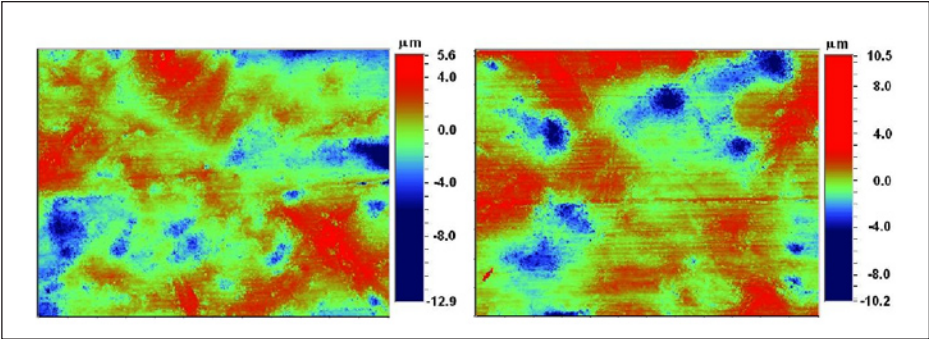
The normalized ACF and the correlation length of the surface heights, L_c , were calculated from the topographic data of each sample using an algorithm developed in MATLAB® 7.0. The correlation length of the three points of each specimen was obtained by averaging randomly chosen 70 profile lines of the topographic map. The lines were taken along the MD at each point.

RESULTS AND DISCUSSION

Table III shows the gloss and surface topography of coated samples calendered at 500 kN/m, 165°C, and six nips. The root mean square roughness and the correlation length of surface heights were determined using the procedure described earlier. Similar measurements were performed on all samples used in this study.

Average microgloss and TAPPI 75° gloss

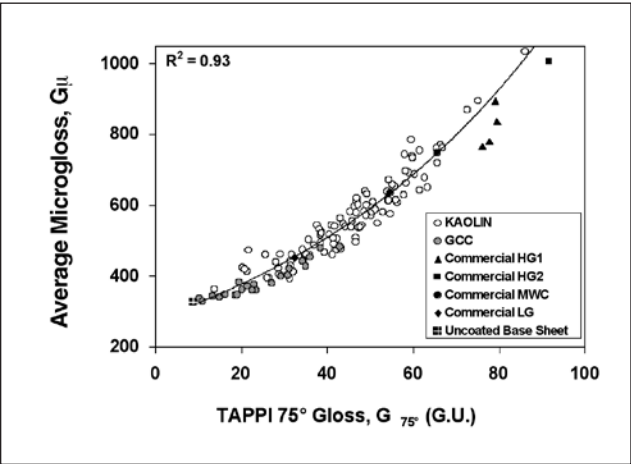
Figure 4 compares the measurements of average microgloss obtained at 23° geometry with the TAPPI 75° gloss for all samples. Each data point corresponds to an average of three specimens. In addition, samples of uncoated base sheet and several commercial coated papers are included in this plot. The average microgloss is given as dimensionless gray level values from a scale ranging from 0 to 1023. This figure shows that despite the large variations in the pigment size, morphology, and calendering conditions, all experimental data fall on the same curve with a correlation coefficient of 0.93. In addition, the laboratory coated sheets and the commercial papers follow the same trend. Similar results have been obtained for ASTM 60° and TAPPI 20° gloss values. The nonlinear relationship between the TAPPI 75° gloss and the



3. Topographic map of coated samples shown in Fig. 2. Coating weight: 15 g/m² (left) and 23 g/m² (right). MD is in the horizontal direction. Image size: 603 μm × 460 μm.

Pigment Code	G_μ	G_{75°	G_{60°	G_{20°	σ_h (μm)	L_c (μm)
K7	518	40.5	12.7	1.8	2.86	38.8
K2S	443	31.3	8.9	1.4	2.49	35.3
K10	630	57.7	23.3	2.8	1.77	49.5
K8	523	38.6	12.6	1.9	2.26	32.8
K4	464	29.0	9.1	1.6	3.04	47.0
K9	564	43.0	13.4	2.1	1.71	52.5
K3N	550	43.7	13.7	2.0	1.78	67.5
GCC1	342	14.8	3.9	1.1	3.41	33.1
GCC2	385	19.5	5.4	1.1	3.36	25.4
GCC3	442	34.2	11.2	1.5	3.15	37.4
GCC4	404	30.8	9.3	1.3	2.95	30.3

III. Gloss and surface statistics of coated samples calendered at 500kN/m, 165°C, and six nips; coating weight = 15 g/m²; pigment characteristics as shown in Table I.

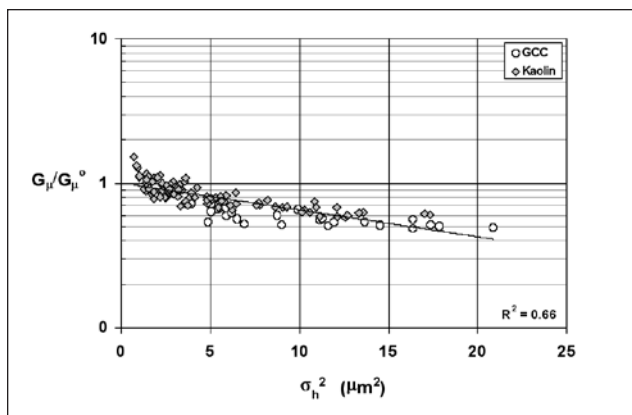


4. Relationship between the average microgloss (G_μ) and the TAPPI 75° gloss (G_{75°) for samples used in this work.

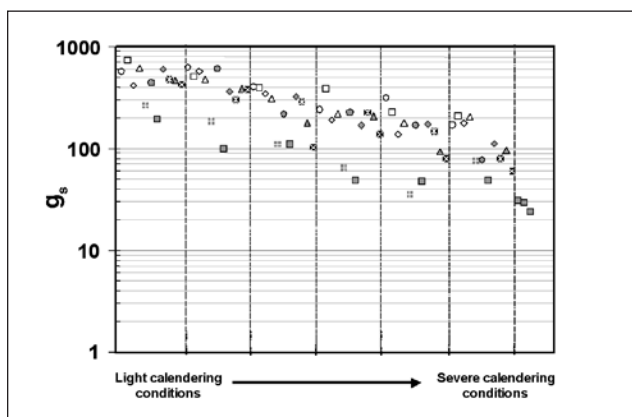
average microgloss is in agreement with what has been reported in the literature [26,32,33] and may be due to the difference in the illumination geometry.

Smooth surface approximation

According to Beckmann and Spizzichino [6], the gloss of relatively smooth surfaces ($g_s \ll 1$) is an exponential function of



5. Relationship between the normalized microgloss, G_{μ}/G_{μ}° , and σ_h^2 for the coated samples.



6. Rayleigh parameter (g_s) for the coated samples as a function of calendering level. $\theta_i = 75^\circ$; coating weight = 15 g/m².

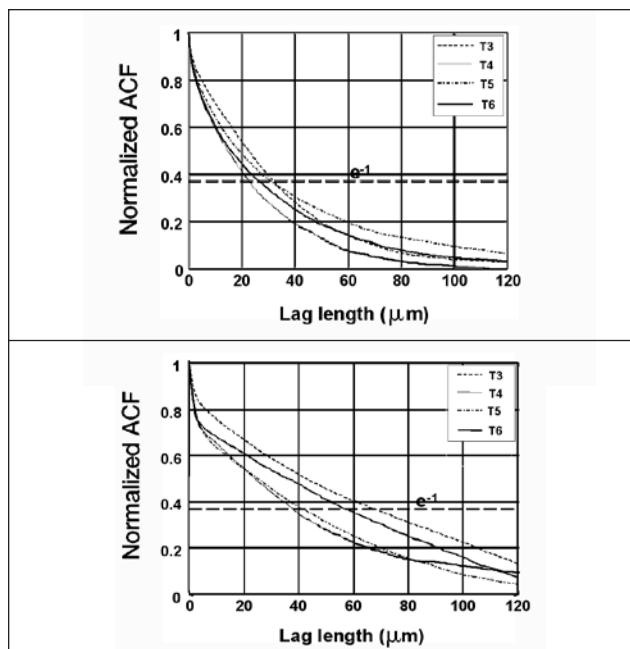
σ_h^2 , as shown by Eq. (5). For $\theta_i = 23^\circ$ (illumination angle of the microgloss setup) and $\lambda = 0.55 \mu\text{m}$, the Beckmann model for smooth surfaces can be reduced to:

$$\frac{G_{23}}{G_{23}^{\circ}} = \exp\left(-442 \sigma_h^2\right) \quad (8)$$

where the ratio G_{23}° is the theoretical gloss at 23° illumination for a perfectly conducting smooth surface. **Figure 5** shows the semi-logarithmic plot of the normalized microgloss (G_{μ}/G_{μ}°) versus σ_h^2 . The relationship is represented by the regression equation given below:

$$\frac{G_{\mu}}{G_{\mu}^{\circ}} = \exp\left(-0.043 \sigma_h^2\right) \quad (9)$$

Although Eqs. (8) and (9) have the same functionality, the coefficients in the exponential term are quite different. This result reveals that the coated samples used in this study fall beyond the applicability of Beckmann model for smooth surfaces. This deviation may be explained by the large surface roughness of the paper samples. **Figure 6** shows the dimen-



7. Normalized ACF for samples coated with (a) fine undelaminated kaolin and (b) coarse delaminated kaolin, and calendered under four different conditions. T3: 110kN/m and 80°C ; T4: 350kN/m and 80°C ; T5: 110 kN/m and 150°C ; and T6 : 350 kN/m and 150°C . Number of nips in all cases is two.

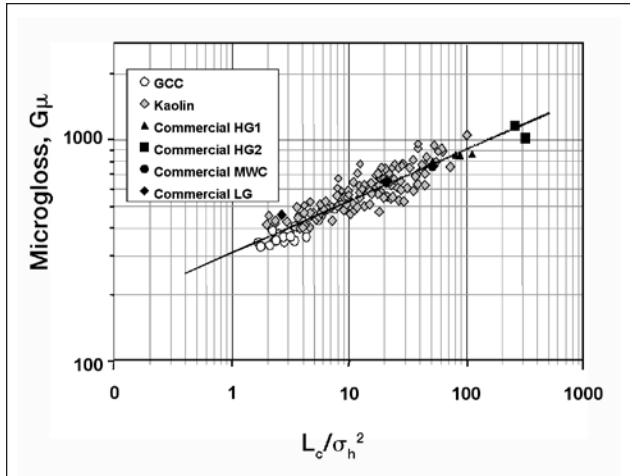
sionless Rayleigh roughness parameter, g_s , for samples with a coating weight of 15 g/m². The parameter g_s was calculated by applying Eq. (1) for an angle of incidence of 75° and $\lambda = 0.55 \mu\text{m}$. From Fig. 6, we see that g_s for coated paper samples is much larger than unity. Similar results were obtained for samples coated at higher coat weights and for the commercial samples. In the case of the commercial samples, the value of g_s ranged from 5 to 570. Therefore, the “smooth surface” approximation is not valid for coated samples used in this study. Instead, paper should be considered as an optically “rough” material, and the intensity of the scattered light in the specular direction is largely determined by the diffusive component of the total scattered field [6,10].

Rough surface approximation

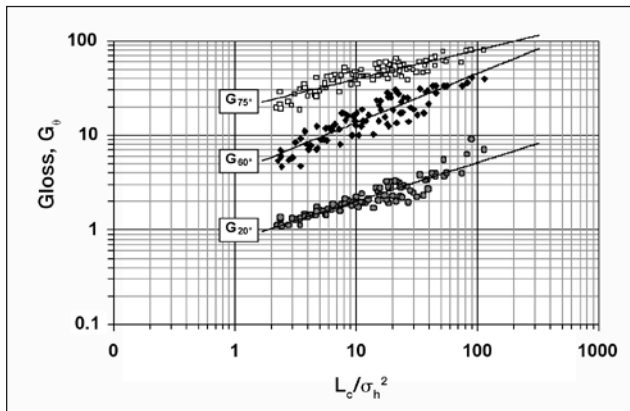
To estimate the gloss of rough surfaces we need to know the ACF of surface topography. **Figure 7** illustrates typical ACFs of several coated samples used in this work. It can be seen that the ACF of paper surface topography may be approximated by an exponential function. Using Alexander-Katz and Barrera’s approximation [10] for the specular reflection of light from rough exponential surfaces, the average microgloss could be expressed by Eq. (6), with $a = 2$:

$$G_{\mu} \propto (L_c / \sigma_h^2)^2 \quad (\text{with } g_s \gg 1) \quad (10)$$

This expression requires both the RMS roughness and the correlation length of the surface topography as input. As seen



8. Relationship between microgloss and the surface texture parameter, L_c/σ_h^2 , as described by Eq. (11).



9. Relationship between standard gloss and the surface texture parameter, L_c/σ_h^2 at 75° (white squares), 60° (black diamonds), and 20° (gray circles).

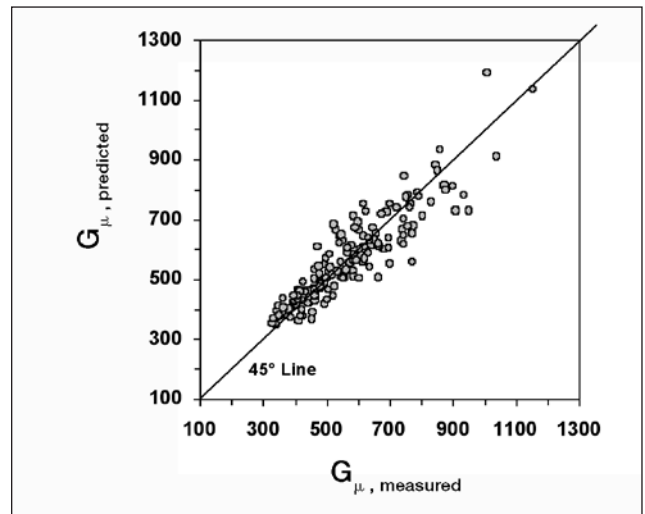
in Fig. 7, calendering condition and pigment characteristics significantly affect the correlation length. Using regression analysis, the relationship between the measured average was found to be:

$$G_\mu = 310 (L_c/\sigma_h^2)^{0.23} \quad (11)$$

Figure 8 is the logarithmic plot of Eq. (11). It illustrates that the relationship between the measured average microgloss versus the surface texture parameter L_c/σ_h^2 is a straight line with a correlation coefficient of 0.84. We found that the four commercial coated samples ranging from low to high gloss obey the same power-law correlation found for the laboratory coated samples. Similar to the average microgloss, the standard gloss at 20°, 60°, and 75° geometries showed a power-law relationship with the RMS roughness and correlation length:

$$G_{\theta_i} = b (L_c/\sigma_h^2)^n \quad (12)$$

where G_{θ_i} represents the standard gloss at angle of measure-



10. Predicted versus measured microgloss.

ment of θ_i . Both b and n are coefficients that depend on θ_i . **Table IV** summarizes their values. **Figure 9** shows the log-log plot of Eq. (12) for three angles of gloss assessment. The exponents in Eqs. (11) and (12) are far from the theoretical value of 2 reported by the Alexander-Katz and Barrera model. Furthermore, the coefficients in these equations depend on the refractive index of the coating layer. Because the refractive indices for the coating materials used in this study are quite similar, the gloss data for all samples can be closely predicted by a single coefficient.

θ_i	b	n
20°	0.8	0.41
60°	4.1	0.52
75°	19.3	0.31

IV. Coefficient, b , and exponent, n , in Eq. (12) for various gloss angles.

To better validate the predictions of the proposed regression models, we directly compared the predicted gloss values to the experimental data. **Figure 10** is an example of such a comparison for the average microgloss. The regression coefficient with respect to the 45° line is 0.67. Similarly, for standard gloss at 75°, 60°, and 20° illumination angles the regression coefficients are 0.61, 0.78, and 0.63, respectively. Considering the wide range of coated samples used in this work, it appears that gloss is mainly dependent on the surface geometry as characterized by L_c/σ_h^2 . Therefore, the ratio L_c/σ_h^2 may be regarded as a key texture parameter determining paper gloss.

CONCLUSIONS

This study shows that conventional theories for light scattering from rough surfaces are unable to predict the gloss of the coated paper samples. Using a semitheoretical approach, we found that the average microgloss and the standard gloss of the coated samples are proportional to $(L_c/\sigma_h^2)^n$ where L_c and σ_h are the correlation length and root mean square of surface height, respectively. This result suggests that gloss is predominantly dependent on the surface geometry of paper. However, gloss and surface topography of paper are affected by coating formulation, coating method, basesheet structure, and calendering conditions. **TJ**

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NOMENCLATURE

a	= exponent in Eq. (6)
ACF	= autocorrelation function
b	= coefficient in Eq. (12)
$B(\tau)$	= autocorrelation function or ACF
$C(\tau)$	= normalized autocorrelation function
e	= Euler constant
G.U.	= gloss units
G_{23}°	= gloss at 23° for a perfectly conducting smooth surface
G_{μ}°	= average microgloss for a perfectly conducting smooth surface
$G_{\theta_i}^{\circ}$	= gloss at θ_i for a perfectly conducting smooth surface
G_{θ_i}	= gloss at θ_i
G_{23}	= gloss at 23°
$G_{20^{\circ}}$	= TAPPI 20° gloss, G.U.
$G_{60^{\circ}}$	= ASTM 60° gloss, G.U.
$G_{75^{\circ}}$	= TAPPI 75° gloss, G.U.
G_{μ}	= average microgloss
$G_{\mu}(i,j)$	= gray level for the element in the i th row and j th column of the captured image with the microgloss setup
g_s	= Rayleigh roughness parameter, Eq. (1)
L	= surface profile length
L_C	= correlation length of surface heights
n	= exponent in Eq. (12)
N	= total number of pixels in the microgloss image
P	= total number of discrete points of a surface profile
x	= position along the surface profile
$z(x)$	= surface height at position x
z_m	= mean surface height
λ	= wavelength of the incident light
θ_i	= angle of incident light
σ_h	= root-mean-square or RMS roughness, μm
τ	= lag length (lateral shifting separation between two exactly same surface features along a line)

INSIGHTS FROM THE AUTHORS

Gloss is a fundamental property of coated papers; however, the relationship between surface texture and gloss of coated papers is not well understood. Because pigment represents between 80% to 95% in weight of any coating color, it is clear that pigment characteristics such as particle size, size distribution, and morphology play a key role in determining the relationship between gloss and surface texture of paper.

Extensive efforts have been dedicated over the years to predicting paper gloss by applying different electromagnetic theories. However, research has been limited to surfaces that are much smoother than typical commercial coated papers. It is still necessary to identify key surface texture parameters that govern the gloss of coated papers of a wide range of roughness values.

One of the most challenging tasks of this research was the collection of statistically meaningful and reliable data. To address this issue, statistical design of experiment was used.

Interestingly, we found gloss to be predominantly dependent on the surface geometry of coated papers, regardless of how the final surface topography of coated paper is achieved.

With the fundamental understanding of the effect of pigment properties and calendering conditions on gloss, papermakers can better optimize the optical response of



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their papers through the control of the pigment attributes. It will also allow pigment suppliers to engineer particles for the improvement of gloss properties.

The next step is to investigate the relationship between gloss and surface texture of printed coated papers.

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