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# Surface gloss measurement using a gonio-spectrophotometric method

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**Abstract** This study compares gloss measurements for high-, medium-, and low-gloss samples using an angle-resolved gonio-spectrophotometer and a commercial glossmeter, demonstrating close agreement between the two instruments within stated measurement uncertainties. The gonio-spectrophotometer's angular scanning capability enables a detailed investigation on how receptor aperture size and positioning influence gloss uncertainty. Using narrow aperture reflectance scans, we characterize the full reflectance distribution of each sample and quantify its impact on calculated gloss values. Results show that accurate estimation of aperture-related uncertainty requires resolving the angular profile of the specular peak, especially when the reflectance curve exhibits significant diffuse scattering. We present a practical procedure for determining gloss uncertainty from the measured reflectance distribution. This approach not only enhances the precision and reliability of gloss measurements across a wide range of gloss levels but also offers a framework that can inform the refinement of international gloss measurement standards.

**Keywords** Gloss, Gonio-spectrophotometer, Glossmeter, Aperture, Uncertainty

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## Introduction

Gloss measurement quantifies the specular reflectance of materials as perceived by the human eye. It is an important practice in evaluating surface characteristics across various industries, influencing both esthetic and functional performance.[1–7] Gloss measurement follows standards such as American society for testing and materials ASTM D523 and international organization for standards ISO 2813 and is expressed in gloss units (GU), where higher values indicate greater glossiness.[8,9]

According to these standards, gloss is measured as the ratio of luminous flux reflected by a sample to that reflected by a glass surface with a refractive index of 1.567 at the wavelength ($\lambda_D$=587.6 nm). Standards refer to a relative measurement method which requires a stable reference sample with a well-defined refractive index. The standards also specify receptor aperture sizes and tolerances for three measurement angles (20°, 60°, and 85°). These geometries are recommended based on measurement conditions and the visual perception of different gloss levels.[8–11]

The use of a reference glossmeter setup for gloss measurement was first introduced by Budde,[1,2,12] followed by other authors who developed their own standard setups, all traceable to defined measurement geometries.[7] The development of these primary glossmeter setups strictly adheres to established standards. However, several limitations and issues in realizing gloss values have been overlooked, largely due to the convenience of using these systems.

Efforts have been made to measure gloss using the bidirectional reflectance distribution function (BRDF) approach,[13] with comparisons conducted against primary glossmeter measurements.[14] While many of these approaches have shown promising results, limitations in certain parameters such as the dimension and position of the receptor aperture continue to influence

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the final gloss values. As a result, ongoing validation of alternative methods against a primary glossmeter remains necessary.[14,15]

The introduction of gloss measurement using absolute specular reflectance-based methods offers a way to address some of the limitations of traditional approaches. A preliminary study on the absolute gonio-reflectometric measurement of gloss and its advantages over primary gloss measurement methods is described by Andor.[16] A European intercomparison involving several institutes, using various techniques including the standard glossmeter and gonio-reflectometric methods, showed good agreement, particularly for high-gloss samples.[17] The demonstrated reliability of absolute specular gonio-reflectometric gloss measurements in the past studies has motivated further investigation into their potential to address challenges in gloss evaluation.

One of the main challenges in gloss measurement arises from the fixed aperture size required by existing standards. This requirement influences the accuracy of measurements, particularly for surfaces with low gloss. Glossy samples reflect light in a narrow specular peak, so most of the reflected light enters the receptor aperture, making the measurement straightforward. In contrast, for medium- and low-gloss surfaces, the reflectance curves are broader, which means that the boundaries defined by the receptor aperture may capture only part of the reflection. This increases measurement uncertainty related to the aperture dimensions. The position of the receptor aperture also plays a role in evaluating total uncertainty. Additional challenges arise when measuring samples with an asymmetric angular distribution of reflected light. To overcome these challenges, a method for determining gloss values that are traceable, angle-resolved, and absolute, along with reliable estimates of uncertainty, would be beneficial.

In this study, our first objective is to determine the gloss values of samples with high, medium, and low gloss using both a commercial glossmeter and our working standard gonio-spectrophotometer. Both instruments are configured in the standard 60° geometry with a fixed receptor aperture, as specified by ISO 2813.[9] This initial comparison is intended to validate our gonio-spectrophotometric method for measuring gloss. After validation, we conduct angular scans within and around the standard receptor dimensions, using a narrow aperture. This approach allows us to determine the shape of the angular reflectance pattern and to assess how variations in the angular distribution of reflected light affect gloss values. Through this process, we can analyze the uncertainty in gloss measurements and examine the impact of small angular deviations on the results. This analysis is particularly important for understanding the effects of wider angular distribution in low-gloss samples and in samples with asymmetric reflectance distributions. This study aims to improve gloss measurement by introducing an angle-resolved, absolute method that addresses the uncertainty of the standard receptor aperture size and position in current standards.

## Background

This study employs the 60° gloss measurement geometry, as specified in ISO 2813,[9] which is commonly used for evaluating surfaces with a wide range of gloss levels. The standard measurement geometry serves as the basis for glossmeters and standard glossmeter setups for the measurement of low- to high-gloss values.[7,12] The source and receptor apertures are defined as 2.5° × 0.75° and 11.7° × 4.4°.

The glossiness of a sample depends on the surface characteristics such as smoothness, coating layers, and substrate quality. Figure 1 illustrates how light is reflected in the specular direction from high- to low-gloss samples. Glossier surfaces reflect light with minimal diffusion (see Fig. 1a), while low-gloss surfaces scatter light more diffusely (see Fig. 1c). This highlights the critical role of receptor aperture dimensions and position in determining how much reflected light reaches the detector and, consequently, the measured gloss value.

## Measurement methodology

Gloss is determined relative to a theoretical standard, defined as a surface of polished glass with a refractive index of $n_D$=1.567 at $\lambda_D$=589.3 nm. For practical realization, reflection of the second surface of a glass plate can be eliminated by black nonreflective coating. The theoretical standard corresponds to a gloss value of 100 GU. The specular reflectance value for the theoretical standard, derived from the Fresnel equations, is 0.100056 for the incident angle $\theta = 60°$.[17]

In our study, we measure the gloss values of three samples representing high-, medium-, and low-gloss levels. The measurements were carried out using a Cary 7000 spectrophotometer equipped with a Universal Measurement Accessory (UMA), which enables goniometric reflectance measurements.[18] The measurement setup is shown in Fig. 2. For comparison, additional measurements were conducted on the same samples using a Rhopoint IQ commercial glossmeter.[19]

In the gonio-spectrophotometer, a quartz tungsten–halogen lamp is used for the measurements. The emitted light from the source passes through a monochromator with a bandwidth of 4 nm, defining a measurement wavelength range from 380 to 780 nm. Measurements are conducted for both s- and p-polarizations by using an automated polarizer located in the illumination arm. Before the light enters the goniometer, it passes through vertical and horizontal apertures to produce a collimated beam of the required size on the sample surface. In the 60° configuration, the beam area on the sample is 6 mm × 2 mm, where the long

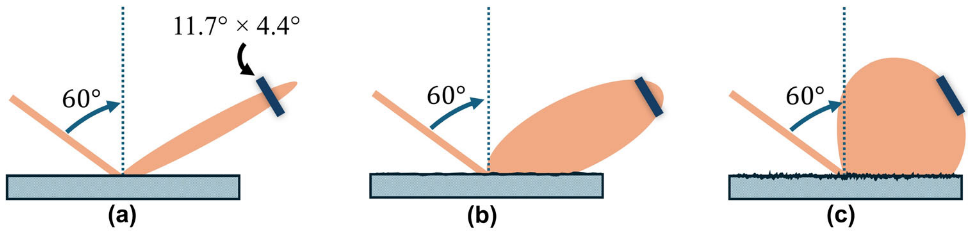


**Fig. 1: Specular reflection from (a) high-gloss, (b) medium-gloss, and (c) low-gloss samples, shown relative to the standard receptor aperture dimensions**

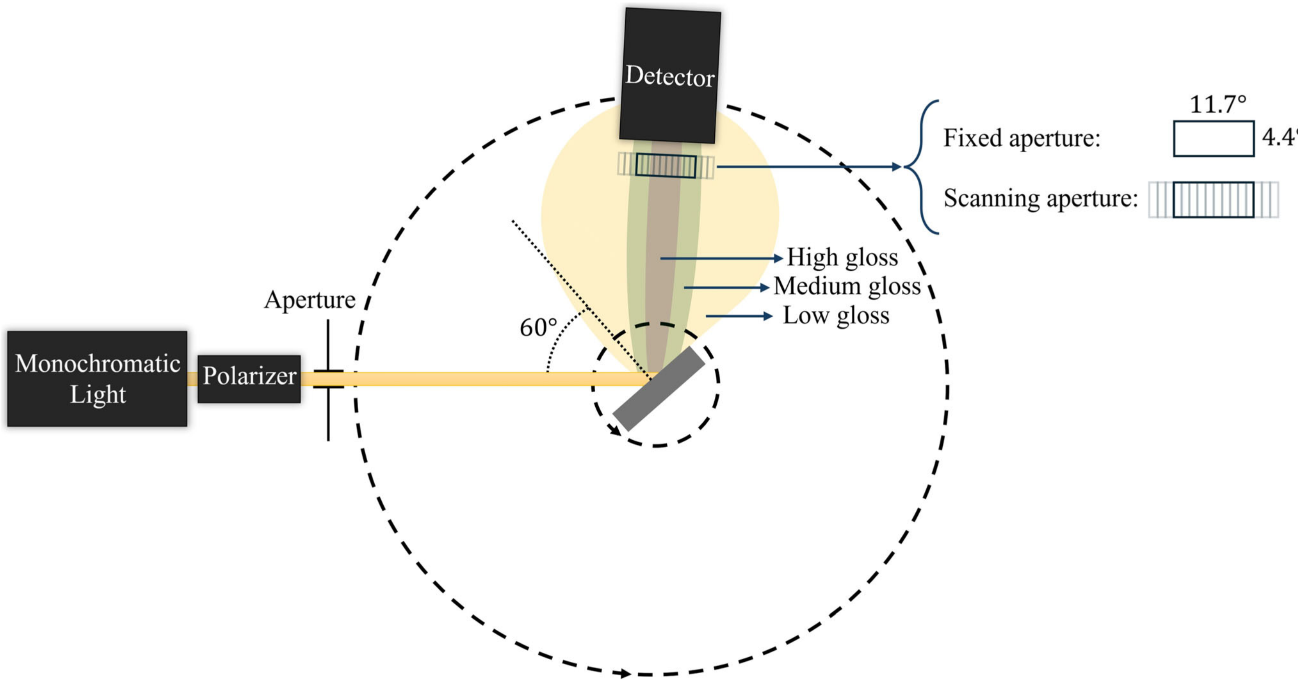


**Fig. 2: Schematic of the gonio-spectrophotometer and gloss measurement setup. Reflections from low-, medium-, and high-gloss samples are shown in different colors. The figure also depicts two measurement methods: (1) using a fixed receptor aperture with standard dimensions and (2) using a narrow aperture to scan the specular peak within and beyond the standard aperture dimensions**

edge is parallel with the plane of incidence. The receptor aperture can be positioned in front of the detector box, which contains an off-axis mirror that focuses the transmitted light onto a silicon photodiode. In the gonio-spectrophotometer, the distance between the sample center and the receptor aperture is 128.5 mm, resulting in a receptor aperture size of 26.33 mm × 9.87 mm. These dimensions correspond to angular extents of 11.7° and 4.4°, parallel and perpendicular to the plane of incidence, respectively.

The absolute specular reflectance of the sample is calculated as

$$R(\theta,\lambda) = \frac{\phi_s(\theta,\lambda) - \phi_d(\theta,\lambda)}{\phi_f(\theta,\lambda) - \phi_d(\theta,\lambda)}, \quad (1)$$

where $\phi_s(\theta,\lambda)$, $\phi_d(\theta,\lambda)$, and $\phi_f(\theta,\lambda)$ represent the reflected, dark, and full signals, respectively, at a given incident angle ($\theta$) and wavelength ($\lambda$). The full signal is measured when the detector is placed in front of the incident beam with the sample removed, and the dark signal is measured by blocking the beam with a cap placed in front of the detector. The final reflectance is computed as the average of the s- and p-polarized reflectance values.

After measuring the specular reflectance $R(\theta,\lambda)$ of the sample at a specified geometry, the luminous reflectance of the sample, $\rho(\theta)$, can be calculated as

$$\rho(\theta) = \frac{\int S(\lambda)R(\theta,\lambda)V(\lambda)\mathrm{d}\lambda}{\int S(\lambda)V(\lambda)\mathrm{d}\lambda}, \quad (2)$$

where $S(\lambda)$ is the spectral power distribution of CIE illuminant C, and $V(\lambda)$ is the luminous efficiency function of photopic vision.[20,21] In the commercial glossmeter, the light source and detection system are designed to physically match the illuminant C and $V(\lambda)$ response. In contrast, our gonio-spectrophotometric approach does not rely on physical filters, as we compute the luminous reflectance by numerically integrating the measured spectral reflectance using tabulated values of $S(\lambda)$ and $V(\lambda)$ from CIE Technical Reports.[20,21]

The gloss value of the test sample $G_t(\theta)$ is calculated as

$$G_t(\theta) = G_r(\theta) \cdot \frac{\rho_t(\theta)}{\rho_r(\theta)}, \quad (3)$$

where $G_r(\theta)$ is the gloss of the working standard sample, and $\rho_t(\theta)$ and $\rho_r(\theta)$ are the luminous reflectance values of the test sample and the working standard, respectively, as defined in Equation (2). The working standard is the calibrated reference sample used to establish the baseline measurement in glossmeters.

The gloss of the reference sample $G_r(\theta)$ is given by

$$G_r(\theta) = G_0(\theta) \cdot \frac{R_r(\theta, \lambda_D)}{R_0(\theta, \lambda_D)}, \quad (4)$$

where $G_0(\theta)$ is the gloss of the theoretical standard (its value is always 100 GU). Parameter $R_r(\theta, \lambda_D)$ is the specular reflectance of the reference sample, and $R_0(\theta, \lambda_D)$ is the specular reflectance of the theoretical standard. The wavelength dependence of the refractive indices of both the theoretical standard and the reference sample is assumed to be identical. The gloss of the test sample can finally be expressed as

$$G_t(\theta) = 100 \cdot \frac{\rho_t(\theta)}{\rho_r(\theta)} \cdot \frac{R_r(\theta, \lambda_D)}{R_0(\theta, \lambda_D)}. \quad (5)$$

In our commercial glossmeter, the gloss value is determined using Equation (5), with an internal calibrated reference sample serving as the measurement baseline. The value of $R_r(\theta, \lambda_D)$ is specified in the manufacturer's certificate and is traceable to the National Institute of Standards and Technology (NIST).

To apply Equation (5) for determining gloss values from our gonio-spectrophotometer measurements, we either need to measure the luminous reflectance of the reference sample alongside the test sample or use modeled values for the reference sample. In this work, $\rho_r(\theta)$ is calculated using the refractive index of a BaK50 glass sample of Zarobila et al.[22]

As shown in Fig. 2, the extent to which reflected light spreads in the specular direction depends on the gloss level of the sample. To assess this effect, we first used a fixed receptor aperture with dimensions specified by ISO 2813. This step validated our gloss measurement method against a commercial glossmeter at a single angle of incidence and detection (60°).

In the second approach, we used a narrow aperture to scan the reflected beam both within and beyond the area defined by the standard aperture. The angle perpendicular to the plane of incidence was maintained at the standard value of 4.4° (aperture height of 9.87 mm), while the angle parallel to the plane of incidence was reduced to 0.78° (narrow aperture width of 2.92 mm). This narrow aperture offers higher resolution, allowing for accurate integration of all scanned signals of the specular peak within the standard aperture area. This approach is particularly important for high-gloss samples. The smaller solid angle also allows for finer scanning steps, making it possible to analyze how the broader light spread from low-gloss samples affects their measured gloss values and to achieve a more reliable evaluation of measurement uncertainty.

## Results and discussion

The samples used are natural color system (NCS) samples,[23] selected from three different gloss ranges. The nominal gloss values, provided by the manufacturer, were determined through visual assessment and validated using their standard instruments (see column 2 of Table 1). The manufacturer specifies relatively large tolerance ranges (also shown in column 2). Our measured values using both the commercial glossmeter

**Table 1: Gloss measurement results from both a commercial glossmeter and a gonio-spectrophotometer operated in two modes: with a fixed receptor aperture (matching standard dimensions) and with a scanning aperture ($G_f$: gloss value measured with a fixed standard aperture, 11.7° × 4.4°, and $G_s$: gloss value obtained by scanning a narrow aperture over the same standard aperture dimensions). Standard uncertainties are quoted for values in columns 3–5**

| Sample | Nominal value (GU) | Glossmeter (GU) | $G_f$ (GU) | $G_s$ (GU) |
|---|---|---|---|---|
| High-gloss | 95 ± 5 | 93.7 ± 0.5 | 93.6 ± 0.7 | 93.6 ± 0.7 |
| Medium-gloss | 75 ± 15 | 69.8 ± 0.6 | 70.3 ± 0.8 | 70.1 ± 0.8 |
| Low-gloss | 12 ± 8 | 13.1 ± 0.4 | 13.4 ± 0.4 | 13.6 ± 0.4 |

and the gonio-spectrophotometer fall well within these limits.

The measurement results obtained from the commercial glossmeter, and their standard uncertainties are listed in the third column of Table 1. The fourth column shows the gloss values measured using our gonio-spectrophotometer (denoted as $G_f$) with a fixed receptor aperture corresponding to the standard 60° gloss configuration (11.7° × 4.4° opening angle) and their associated uncertainties. The fifth column presents gloss values obtained by scanning with the narrow aperture (0.78° × 4.4°) parallel to the plane of incidence over the full angular range (11.7°) by stepping in 0.78° intervals (denoted as $G_s$).

Figure 3 shows the difference between the commercial glossmeter and the gonio-spectrophotometer measurements using the standard fixed aperture. As shown, the results from both devices are in close agreement within the combined uncertainties, validating the accuracy of our gonio-spectrophotometer when using the standard receptor aperture.

Furthermore, the results in Table 1 demonstrate very good agreement between the measurements obtained using the fixed and scanning apertures within the standard dimensions (columns 4 and 5). This confirms both the accuracy of the fixed aperture configuration and the reliability of the measurement procedure. It also supports the use of the scanning aperture approach to evaluate the angular spread of reflected light and its influence on gloss value determination.

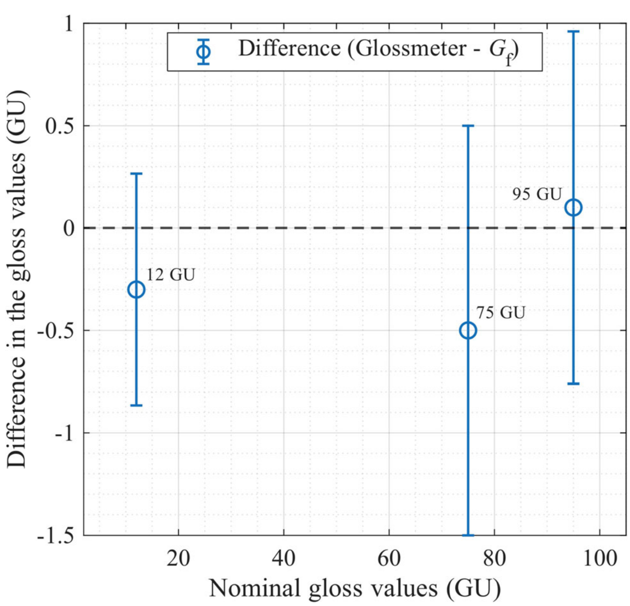


**Fig. 3: Comparison of gloss measurements of the commercial glossmeter and the gonio-spectrophotometer with the fixed standard receptor aperture. Error bars represent combined standard uncertainties**

Figure 4 shows the reflectance profiles of the samples, measured by scanning with the narrow aperture at a wavelength of 555 nm. Within the standard aperture region, indicated by the two vertical dashed lines, the spectral reflectance profiles differ significantly according to the gloss level of the samples. Each data point represents the average reflectance of s- and p-polarized light measured within a small aperture area of 0.78° × 4.4°. The high- and medium-gloss samples (Fig. 4a and b) display a pronounced peak at the center of the specular region, with reflectance values decreasing rapidly toward the edges of the standard aperture. In contrast, the low-gloss sample shows a more diffuse reflectance profile around the specular angle (Fig. 4c).

## Uncertainty evaluation

When using the scanning aperture, both the aperture dimensions and scanning intervals must be carefully selected to ensure accurate integration over the sharp specular peak typical of high-gloss samples. The results in Table 1 show good agreement between the fixed and scanning aperture measurements, indicating that the chosen scanning parameters effectively capture the specular reflection. These findings support the validity of the scanning approach and confirm that the chosen narrow aperture dimensions are suitable for reconstructing reliable gloss values across low- to high-gloss samples. With the angular scanning capability, we can now assess the uncertainty in gloss measurements arising from the dimension and position of the receptor aperture. Depending on the reflectance curve of the sample in the specular direction, these sources can contribute significantly to the uncertainty of gloss measurements. However, they are often assumed to be negligible under the expectation that samples are predominantly specular rather than diffuse.[22]

For the glossier samples, the intensity of specular reflection is much higher at the center than at the edges of the standard aperture. As a result, when using a fixed standard receptor aperture, the gloss value of a high-gloss sample is less affected by small changes in aperture dimensions and position, because most of the reflected light is concentrated within the aperture area. In contrast, a low-gloss sample displays a broader and flatter reflectance distribution, making its gloss measurement more sensitive to even minor changes in aperture size and position. The uncertainty associated with the position of the receptor aperture is influenced by asymmetry of the angular reflectance distribution.

In our uncertainty evaluation, we assess the effects parallel to the plane of incidence based on Fig. 4. In the perpendicular direction, we assume similar angular dependence as in Fig. 4, because studies have shown that the in-plane and out-of-plane reflectance values of various sample types are relatively similar, provided the samples are flat and do not exhibit dominant patterns or scratches.[24–27] The isotropy of our samples

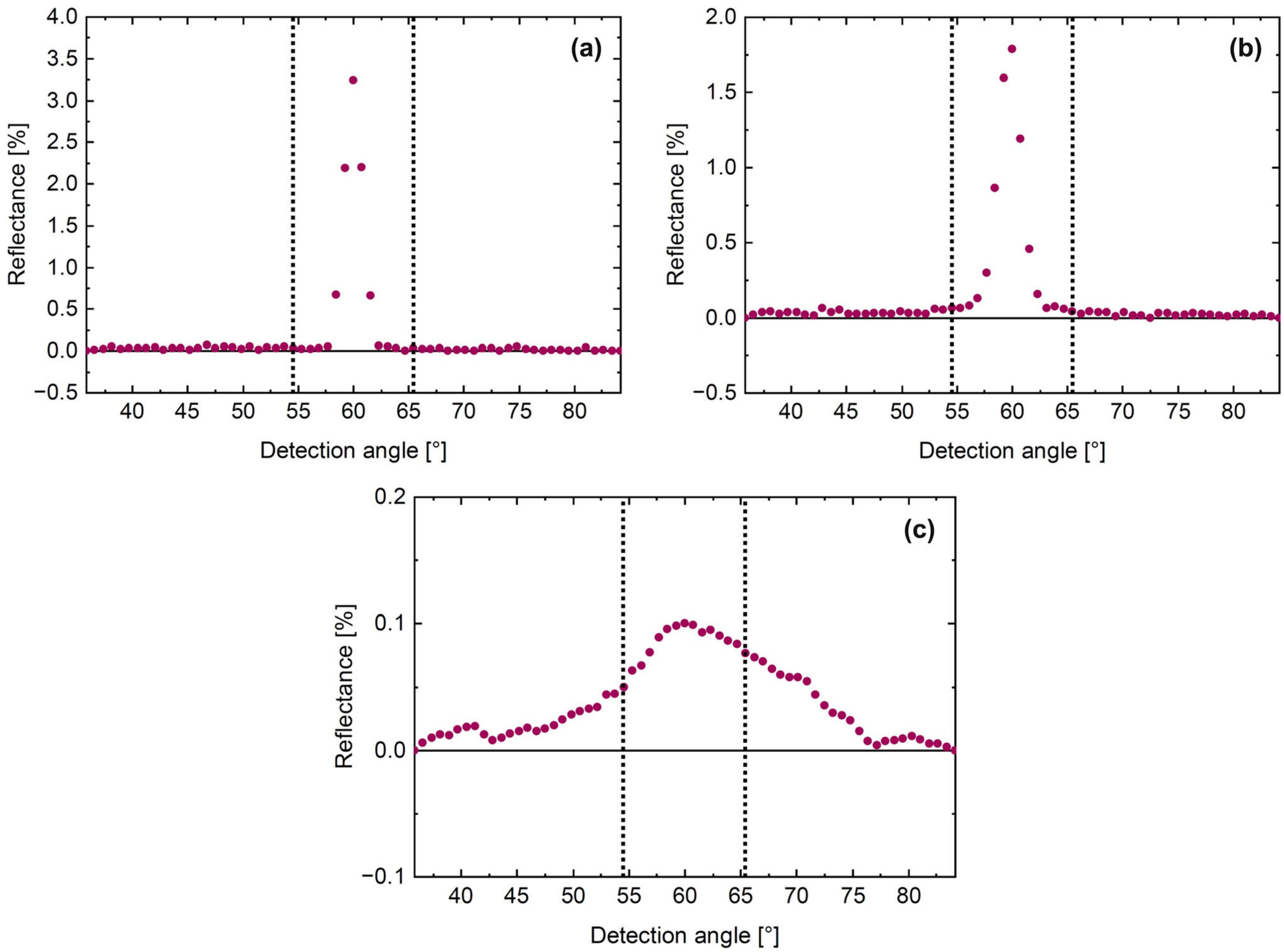


**Fig. 4: Angular reflectance values for (a) high-gloss, (b) medium-gloss, and (c) low-gloss samples as a function of detection angle at 555 nm. Each data point represents a measurement within an aperture of 0.78° × 4.4°, parallel and perpendicular to the plane of incidence, respectively. The dashed lines indicate the boundary of the standard aperture dimension parallel to the plane of incidence. Angular reflectance measurements are performed up to 60° ± 24.18°, beyond which the reflectance is zero for all samples**

was confirmed by measuring gloss at rotational positions of 0° and 90°, with the difference in gloss values between these orientations being less than 0.1 GU.

### *Gonio-spectrophotometer*

So far, we have demonstrated the influence of light spread around the receptor aperture on the gloss values of different samples. Building on this, we now use our angular scanning method to evaluate the gloss measurement uncertainty. The uncertainty budget is presented in Table 2 and discussed in detail in the following subsections. The combined standard uncertainty is calculated as the root sum of squares of all individual uncertainty components. This approach assumes that the uncertainty sources are independent.

*Uncertainty due to the aperture dimensions*

To evaluate this uncertainty component, we first determine the uncertainty in the opening angle of the receptor aperture. The aperture is fabricated using a 3D printing method, and its dimensions are measured with a caliper, yielding a standard measurement uncertainty of 0.1 mm. This corresponds to an angular uncertainty of 0.18°. The ratio of signals with the nominal aperture and with a larger aperture extending ± 0.05 mm beyond the nominal aperture boundaries is then calculated, and the effect on the gloss values for each sample is evaluated.

The left and right boundaries of the aperture are located at 60° ± 5.85° in the plane of incidence. From Fig. 4, it is evident that the angular reflectance curves of the high- and medium-gloss samples fall well within these boundaries in the parallel direction and decay

**Table 2: Uncertainty budget for gloss measurements using the gonio-spectrophotometer. The aperture width refers to the dimension parallel to the plane of incidence, while the aperture height refers to the dimension perpendicular to the plane of incidence. Standard uncertainties are listed for all components**

| Sample | Aperture width | Position parallel | Aperture height | Position perpendicular | Reflectance measurement | Repeatability | Combined standard uncertainty |
|---|---|---|---|---|---|---|---|
| | (GU) | (GU) | (GU) | (GU) | (GU) | (GU) | (GU) |
| High-gloss | 0.00 | 0.00 | 0.08 | 0.03 | 0.4 | 0.6 | 0.7 |
| Medium-gloss | 0.00 | 0.00 | 0.5 | 0.2 | 0.3 | 0.5 | 0.8 |
| Low-gloss | 0.1 | 0.03 | 0.4 | 0.04 | 0.05 | 0.1 | 0.4 |

sharply beyond them. In contrast, for the low-gloss sample, part of the reflectance curve extends past the left and right aperture boundaries. As a result, this uncertainty component in the plane of incidence affects the low-gloss sample but has negligible influence on the high- and medium-gloss samples, as shown in the second column of Table 2.

The top and bottom boundaries of the aperture are located at ± 2.20° perpendicular to the plane of incidence. The gloss uncertainty in this direction is calculated in the same way as for the parallel direction, based on Fig. 4, under the assumption that the in-plane and out-of-plane reflectance values are relatively similar.[24–27] For the high-gloss sample, the specular peak is almost entirely contained within the aperture boundaries, resulting in a low contribution to the total uncertainty. For the medium-gloss sample, the aperture boundaries encompass a steep section of the reflectance curve, resulting in a significant uncertainty. For the low-gloss sample, the reflectance curve is flatter close to the maximum, leading to smaller uncertainty values compared with the medium-gloss sample. Numerical values of these uncertainty components are reported in the fourth column of Table 2. Rotating the receptor aperture of Fig. 2 by 90° around the direction of the reflected beam would allow the scanning aperture to fully cover the reflectance of the medium-gloss sample in direction perpendicular to the plane of incidence, resulting in lower uncertainties.

*Uncertainty due to the detection angle*

This component of uncertainty is due to the positioning accuracy of the aperture and is linked to the inherent uncertainty in the goniometer section of the measurement device. Based on the alignment precision of the gonio-spectrophotometer, the detection angle uncertainty is 0.1°.[28] In addition to this alignment component, the aperture's position uncertainty relative to the detector center, which is 0.1 mm, affects the total uncertainty in the detection angle. The combined detection angle uncertainty is then 0.2°. To assess its effect on gloss values, the evaluation window is shifted by ± 0.2° from its nominal position. The resulting gloss values are then calculated and compared with the nominal values.

Our angular scanning approach simplifies this evaluation because detailed reflectance distributions are already available for each sample. In the parallel direction, shifting the boundaries to the left or right has little effect, as the peaks for the high- and medium-gloss samples remain within the boundaries, and the impact on the low-gloss sample is also minimal. This result is shown in the third column of Table 2.

In the perpendicular direction, the effect is similar to that observed for the aperture dimension uncertainty. For the medium-gloss sample, the top and bottom boundaries intersect a portion of the reflectance curve that exhibits a degree of asymmetry. Consequently, shifting the aperture position upward or downward has a greater impact, as indicated in the fifth column of Table 2.

*Uncertainty due to reflectance*

This uncertainty component arises from the device's capability in reflectance measurements, which can be affected by factors such as noise, stray light, wavelength scale, and other instrumental effects. Taking these factors into account, the relative reflectance uncertainty is 0.4% within the wavelength range used in our measurements.[28] This value is then used to calculate the corresponding uncertainty in gloss units for each sample, as reported in the sixth column of Table 2.

*Repeatability*

The uncertainty due to repeatability was assessed by performing four separate reflectance measurements for each sample, removing and re-positioning the sample between each run. Gloss values were calculated for each measurement, and the repeatability contribution

**Table 3: Uncertainty budget for gloss measurements using the commercial glossmeter**

| Sample | Calibration uncertainty (GU) | Repeatability (GU) | Combined standard uncertainty (GU) |
|---|---|---|---|
| High-gloss | 0.2 | 0.5 | 0.5 |
| Medium-gloss | 0.2 | 0.6 | 0.6 |
| Low-gloss | 0.2 | 0.3 | 0.4 |

to the overall uncertainty was estimated as the standard deviation of these repeated gloss values.

### *Glossmeter*

Table 3 presents the uncertainty budget associated with the commercial glossmeter measurements.

The uncertainty components considered for the glossmeter include calibration uncertainty and measurement repeatability. Calibration uncertainty is provided by the manufacturer. Repeatability uncertainty is calculated as the standard deviation of glossmeter readings from 10 repeated measurements taken at the same location on the sample, both in the short and long terms. Each measurement is performed after repositioning the glossmeter and re-establishing the baseline.

Nonuniformity of the gloss samples was also evaluated to ensure the reliability of gloss values when comparing measurements using the gonio-spectrophotometer and the commercial glossmeter. The measured nonuniformity was found to be much smaller than the repeatability of measurements.

## Conclusions

This study demonstrates that a gonio-spectrophotometer operated in fixed aperture and angular scanning modes provides gloss values consistent with those from a standard-compliant commercial glossmeter across low- to high-gloss values. This agreement substantiates angle-resolved use of the instrument. Angle-resolved scans with a narrow receptor aperture show that measurement accuracy is governed by the specular reflectance distribution and influenced by aperture dimensions and placement. Based on these findings, an uncertainty estimation procedure is presented that first acquires the angular reflectance curve, then combines it with characterized instrument and aperture uncertainty components, and finally propagates these contributions to the reported gloss uncertainty. The procedure yields transparent uncertainty budgets for aperture dimensions and positioning, improves measurement reliability, and supports compliance with current gloss standards while informing their refinement.

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**Conflict of interest** The authors declare that they have no conflict of interest.



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