A reference instrument for specular gloss measurements

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Abstract. Specular gloss is the perception by an observer of the mirror-like appearance of a surface. The glossmeter provides a quantifiable way of measuring the specular gloss. A setup for determining the specular gloss of non-textured coatings on plane, opaque substrates has been introduced. The measurement results using our apparatus have been compared with that obtained by NRC. The comparison results validate the accuracy of our instrument.

1. Introduction
Specular gloss has been widely used to characterize the ability of a surface to reflect light specularly [1]. Specular gloss is the ratio of luminous flux reflected from an object to that reflected from a reference in the specular direction. The reference is a highly polished and perfectly flat black glass with a refractive index of 1.567 at a wavelength of 587.6 nm.

The American Society for Testing and Materials (ASTM) D523 and the International Standards of Organization (ISO) 2813 specify a standard test method for determining the specular gloss of coatings using the three geometries of 20°, 60° or 85°. Both National Research Council of Canada (NRC) and National Institution of Standards and Technology (NIST) have developed glossmeters to measure the specular gloss [2-6].

In this paper, we propose a setup for determining the specular gloss of non-metallic specimens. We have compared the measurement results using our apparatus with that obtained by NRC. The comparison results validate the accuracy of our instrument.

2. Theory
For glass plates with a refractive index deviating from 1.567, the gloss is calculated by means of a correction factor K to K × 100 GU.

\[ K(n, \alpha_i) = \frac{\rho(n, \alpha_i)}{\rho(1.567, \alpha_i)} = A(\alpha_i) \times \left[ 2 \rho(n, \alpha_i) \right] \]  

(1)

where
\( n \) is the refractive index of the standard plate at the wavelength used;
\( \alpha_i \) is the measuring angle, in degrees;
\( \rho(n, \alpha_i) \) is the total reflectance for the refractive index \( n \) and the measuring angle \( \alpha_i \);
\( \rho(1.567, \alpha_i) \) is the total reflectance for the refractive index 1.567 and the measuring angle \( \alpha_i \);
$A(\alpha_i)$ is a factor only depending on $\alpha_i$;
$K(n,\alpha_i)$ is the correction factor for the refractive index $n$ and the measuring angle $\alpha_i$.

3. Design
The instrument has been developed for specular gloss measurements using the three geometries of 20°, 60° or 85° in accordance with ASTM D523 and ISO 2813 specifications. The apparatus is a monoplane goniometer with a fixed source arm, a rotating sample stage and a rotating receptor arm.

3.1. Source and receptor arms
The source arm consists of a light source furnishing an incident beam, a condenser lens focusing the beam at the source field aperture, and a source lens collimating the beam onto the surface of the specimen. The receptor arm is composed of a receptor lens focusing the reflected beam at the receptor field aperture, and a photometer receiving the required pyramid of rays collected by a collector lens. The receptor is a photosensitive device responding to visible radiation. The source and receptor arms of the instrument are plotted in Figure 1.

![Source and receptor arms](image)

Figure 1. The source and receptor arms of the instrument.

3.2. Rotary stages
Since the old instrument suffers poor measurement repeatability due to the human interference, a novel fully automated reference and sample holder system involving three independent rotary motions has been developed, which is shown in Figure 2. Because of the fixed source arm, the first rotary stage moves the receptor arm and defines the centre position of the optical axis. It improves the stability of the light source and reduces associated vibrational problems. Meanwhile, the second rotary stage moves the sample stage via an extension arm. The cooperation between above two rotary stages achieves three geometries of 20°, 60° or 85°. The self rotation of the sample stage interchanges the reference with the sample by the third rotary stage, which significantly improves the specular gloss measurement repeatability of the instrument.
4. Results

The measurement procedure of specular gloss typically requires an operator to interchange sample and gloss reference standard for each cycle. To verify the specular gloss measurement accuracy of the instrument, intercomparison measurements have been performed with NRC. The intercomparison specimens consist of black glass and ceramics plates, whose gloss values range from high to matt. The intercomparison results are shown in Table 1. For the instrument of Shanghai Institute of Measurement and Testing Technology (SIMT), the combined expanded uncertainty \((k=2)\) is 0.6 gloss unit (GU) for all samples. For the apparatus of NRC, the combined expanded uncertainty \((k=2)\) ranges from 0.30 to 1.00 GU, depending on the measurement geometry.

| Geometry(°) | S/N     | SIMT(GU) | NRC(GU) | \(E_n\) |
|------------|---------|----------|---------|---------|
|            |         | Gloss    | \(U(k=2)\) | Gloss    | \(U(k=2)\) |         |
| 20         | 167A69  | 20.7     | 0.6     | 21.07   | 0.31     | -0.55   |
|            | 1131H76 | 38.8     | 0.6     | 38.93   | 0.33     | -0.19   |
|            | 167A87  | 68.3     | 0.6     | 68.88   | 0.32     | -0.85   |
|            | 167A98  | 96.5     | 0.6     | 96.49   | 0.31     | 0.01    |
|            | 167A21  | 19.5     | 0.6     | 18.97   | 0.31     | 0.78    |
|            | 167A47  | 44.7     | 0.6     | 45.03   | 0.30     | -0.49   |
| 60         | 167A69  | 68.6     | 0.6     | 68.76   | 0.31     | 0.01    |
|            | 167A98  | 97.6     | 0.6     | 98.12   | 0.31     | -0.77   |
|            | 167A12  | 20.9     | 0.6     | 20.45   | 1.00     | 0.39    |
|            | 167A21  | 40.2     | 0.6     | 39.23   | 1.00     | 0.83    |
| 85         | 167A47  | 66.5     | 0.6     | 66.22   | 1.00     | 0.24    |
|            | 167A98  | 99.2     | 0.6     | 99.73   | 0.30     | -0.79   |

The intercomparison results in accordance with the corresponding combined expanded uncertainty have been evaluated by the normalized deviation \(E_n\), which are plotted in Figure 3.
Figure 3. The intercomparion results performed with NRC: (a) 20°; (b) 60°; (c) 85°.

It can be seen that the intercomparison results between SIMT and NRC are satisfied for all three geometries of 20°, 60° or 85°. The maximum error of 0.97 GU occurs at the geometry of 85° for the 167A21 sample. The angles and tolerance of the receptor specified by ASTM D523 and ISO 2813 at 85° geometry is 4.0°±0.3° in parallel to plane of reflection and 6.0°±0.3° perpendicular to the plane of reflection, which is higher than those at 20° and 60° geometries. The intercomparison results suggest that the receptor aperture angle tolerance of 85° geometry may need to be stricter to improve the intercomparison agreement for specular gloss measurements.

5. Conclusions
A reference instrument with a combined expanded ($k=2$) uncertainty of 0.6 GU for specular gloss measurements has been proposed. The intercomparison measurements have been performed using our apparatus with that obtained by NRC. The intercomparison results demonstrate good agreement and validate the accuracy of our instrument.

6. Acknowledgements
This work was supported by the Science and Technology Program of Shanghai Municipal Bureau of Quality and Technical Supervision (No. 2017-08).

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