BRDF variability of typical diffuse reflectance standards between 380 nm and 1700 nm

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Comparison of the reflectance properties of different diffuse reflectance standards provides guide to select the standard most adequate for a given application. IO-CSIC and PTB have studied the variation of the spectral BRDF with respect to the standard bidirectional geometry 0°:45° of the four most typical diffuse reflectance standards (barium sulphate, opal glass, ceramic tile and Spectralon), within the spectral range [380-1700] nm. IO-CSIC measured the variation in-plane spectral BRDF at several incidence angles, whereas PTB measured its out-ouf-plane variation at a fixed 45° incidence angle.

INTRODUCTION

The assumption that the reflectance properties of diffuse reflectance standards are identical to those of perfectly reflecting diffuser (PRD) makes these standards adequate to characterize the reflectance factor of any surface at any irradiation/collection geometry by simple comparison. However, this assumption is only true within certain limits, and, in some cases, the requirement level imposes being more specific about the slight difference in reflectance between a given diffuse reflectance standard and the PRD. In recent years, National Metrology Institutes (NMIs) and other research centres have developed complex robot–based goniospectrophotometers to measure the bidirectional reflectance of surfaces with as few geometrical restrictions as possible [1-3], even facilitating measurements at out-of-incidence-plane geometries ('out-of-plane' to be short). We investigated the variation of the Bidirectional Reflectance Distribution Function (BRDF) with respect to the bidirectional geometry 0°:45° for the four most typical diffuse reflectance standards (barium sulphate, opal glass, ceramic tile and Spectralon), whose detailed descriptions in terms of reflectance can be found in [4]. PTB and IO-CSIC have available their own diffuse reflectance standards made of the above-mentioned materials. They had previously and independently measured their reflectance at bidirectional geometries using their own goniospectrophotometers [1, 3], and had presented their results within the spectral range [380-780] nm [4, 5]. PTB and IO-CSIC have extended the spectral range of their instruments to 1700 nm as a first step to calibrate multi-angle diffuse reflectance standards. Both institutes measured the spectral BRDF between 380 nm and 1700 nm with independent experimental procedures. The variation of the reflectance within this extended spectral range for the four diffuse reflectance standards is presented and thoroughly discussed.

BRDF MEASUREMENTS

A measurement geometry is specified by the spherical coordinates of their irradiation and collection directions. θ_i and θ_r angles are the polar coordinates for irradiation and collection directions, respectively, whereas ϕ_i and ϕ_r angles are their azimuth coordinates. We fixed $\phi_i = 0°$ in all cases, and, therefore, the value of ϕ_r can be regarded as the difference between the azimuth angles of the irradiation and collection directions. The goniospectrophotometer GEFE available at IO-CSIC was previously described in [1-2], The goniospectrophotometer facility at PTB is described in detail in [3].

RESULTS

The BRDF spectra [$f_r(\theta_i, \phi_i; \theta_r, \phi_r; \lambda)$] were normalized with respect to the BRDF spectrum at the standard bidirectional geometry 0°:45°, which will be used as reference geometry. This normalization ($f_{r,rel}$) allows the variation of the spectral BRDF to be better shown. Two descriptors are derived from ($f_{r,rel}$) to account for the non-Lambertian behaviour and the spectral variation with respect to the standard geometry 0°:45°. They are defined, respectively, as:

$$\Delta_r f_r = \langle f_{r,rel} \rangle_\lambda - 1 \qquad (1)$$

and

$$\delta f_{\mathrm{r}} = STD_{\lambda}\left(\frac{f_{\mathrm{r,rel}}}{\langle f_{\mathrm{r,rel}}\rangle_{\lambda}}\right) \quad (2)$$

where $\langle f\rangle_{\lambda}$ denotes spectral average of f, and $STD_{\lambda}(f)$ its standard deviation. We will use these variables to describe the variation of the spectral BRDF with respect to its measurement at the standard geometry 0°:45°, for the four diffuse reflectance standards studied here. Whereas $\Delta_{\mathrm{r}} f_{\mathrm{r}}$ provides the relative variation of the average f_{r} with respect to the geometry, δf_{r} represent the relative spectral variation for each geometry. These variations are shown in Figs. 1-2, and will be separately described for the visible and near-infrared spectral ranges.

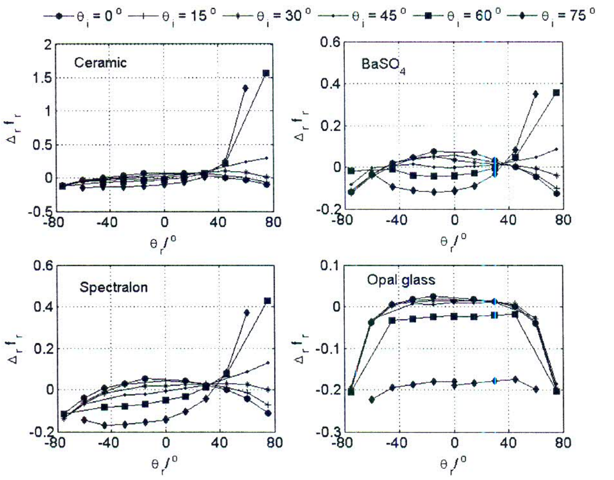

Figure 1. IO-CSIC results on the dependence of the variable $\Delta_{\mathrm{r}} f_{\mathrm{r}}$ on the incidence angle for every diffuse reflectance standard.

CONCLUSIONS

Two descriptors ($\Delta_{\mathrm{r}} f_{\mathrm{r}}$ and δf_{r}) have been proposed to give insight about deviation of commonly used diffuse reflectance standards with respect to the PRD. The measured values allow the uncertainty due to this deviation to be accounted when these standards are used at other geometries than the standard geometry 0°:45°, under the PRD assumption. We have found that out-of-plane geometries might present more uniform reflectance properties than those in the plane of incidence, which may be exploited for calibrations out of the standard geometry. Strong discrepancies were found between the opal glass samples available at IO-CSIC and PTB, because the surface of the opal glass used by IO-CSIC is polished, whereas the one used at PTB is matte. Polishing seems to avoid large variations of reflectance out of the specular geometry. In the case of $BaSO_4$, we have detected discrepancies too, which may be due to the different process of preparation of the specimen. A methodology based on the calculation of descriptors allows a simple and helpful comparison of the reflectance properties of different diffuse reflectance standards, providing a guide to select the most adequate for each application. A detailed analysis of the spectral BRDF variation for the four studied diffuse reflectance standards will be presented in this contribution.

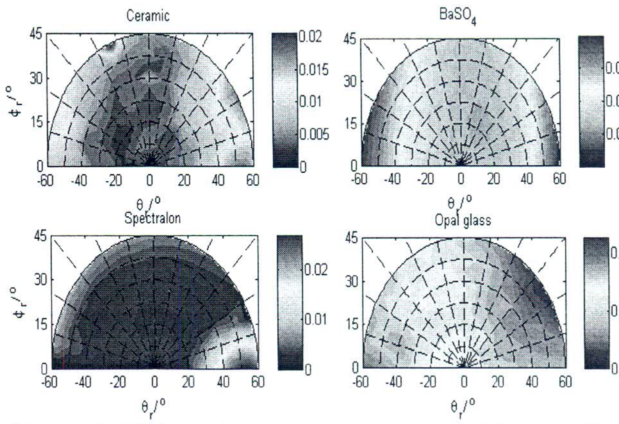

Figure 2. PTB results on the dependence of the variable δf_{r} on the collection direction for every diffuse reflectance material, with a fixed incidence angle of 45°.

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