# Determining the shape of reflectance reference samples for curved surface reflectors

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**Foils made of different materials are often used as reflective insulators. Many manufacturers aim to accurately measure their optical properties to estimate and improve their performance. However, flat reflectance reference samples used in measurements do not correctly represent reflective insulators and cause discrepancy between different measurement techniques. Current work presents a method for modelling surface shape of appropriate reflectance reference samples that could be produced by additive manufacturing. The method is based on studying the reflection distribution of reflective insulators and is described with an example of aluminium foil. Method's performance is validated using Monte-Carlo simulations.**

## INTRODUCTION

Precise characterization of reflectivity of reflective insulation products for buildings is important for manufacturers of those products. However, recent intercomparison of reflectivity measurement techniques organized by the standardization working group CEN/TC 89/WG 12 has shown large differences of total hemispherical reflectivity results deviating by 6 % (from 0.92 to 0.98) on the same reflective material. The reasons of these differences are yet to be explained, but one of them ought to be a reflectance reference sample that doesn't represent the measurement object closely enough.

As indicated in the intercomparison, the plane mirrors or diffusing reflectance samples that are usually used for calibration of portable instruments may not be the best calibration targets. They are quite far from actual measurement targets - aluminized or aluminum foils that are usually used as external surfaces of reflective insulators. They usually have non-flat (battered and crumpled) surfaces and their comparison with flat reference standards may introduce some additional variation in reflectivity measurements.

Production of appropriate reference samples seems to be an obvious solution for this problem. Modern additive manufacturing methods allow to produce objects from almost any material with almost any size and shape. The questions that remain are that what should be the sample's surface shape so that it would exhibit reflectance properties similar to the reflective insulation products and what would be a suitable manufacturing method.

Present article tackles these problems by introducing a method to determine a shape of the new reflectance reference sample that could be manufactured by precise additive manufacturing or by some other method.

## METHOD

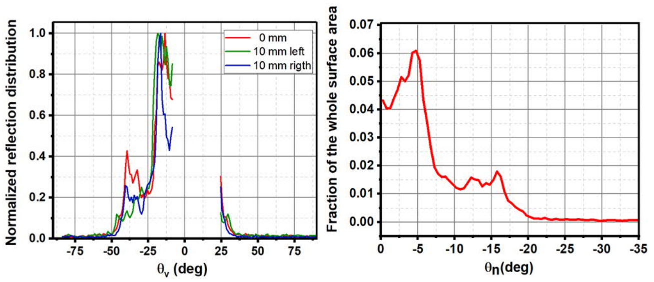


**Figure 1.** Reflection distribution of mesh-reinforced foil (left) and corresponding distribution of surface normals (right).

To determine the shape of desired reflectance reference sample, a reflection distribution of mesh-reinforced foil insulator was measured by an absolute gonioreflectometer developed at Laboratoire national de métrologie et d'essais (LNE) [1]. From the results, (see Figure 1) a corresponding facets' normals distribution function of crumpled aluminium was derived by averaging measurements and assuming that light reflected specularly from each individual microfacet. Next, an element of the reflectance reference sample surface profile was constructed. It consisted of coaligned linear segments whose slope and length corresponded to a particular facet normal and probability to encounter it defined by normals' distribution function. At the same time, to reduce selfshadowing effect and avoid microstructures that are impossible to produce, only sharp angles between facets' were allowed. This resulted in the shape depicted in Figure 2 (left):

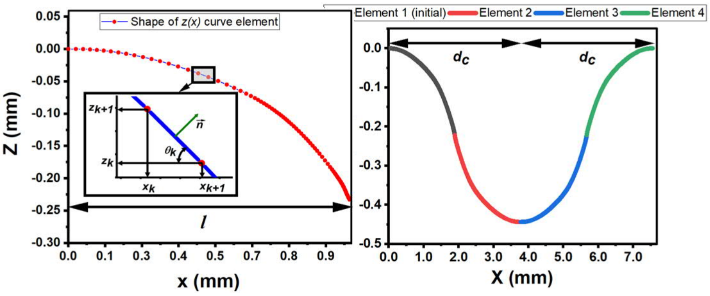


**Figure 2.** The shape of a single element corresponding to derived distribution of facets' normals (left) and waveform constructed of these elements (right)

Following the same principles, derived elements were flipped and shifted to obtain single period of waveform shown in Figure 2 (right). Finally, multiple periods were stacked together and stretched along Y-axis to form a 3D model (Figure 3) of structured reflectance reference sample with angular reflection distribution of a mesh-reinforced aluminium foil insulator.

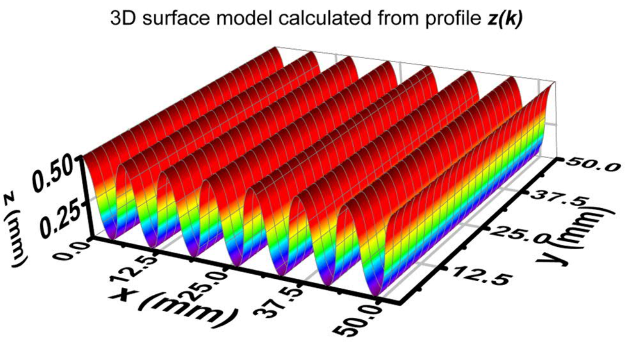


**Figure 3.** 3D model of structured reflectance reference sample for a mesh-reinforced aluminium foil insulator

The length of the waveform period was estimated from the parameters of LNE's goniometer [1]. It illuminated the measured insulator sample with the beam of 12 mm in diameter. In this case, mean illuminated distance calculated from the average length of chords is $\overline{a_b} = 7.71$ mm. Assuming that there is an equal number of facets with normals pointing to the left and to the right of the sample, $d_c = \bar{a}_b/2 = 3.86$ mm is the characteristic distance within which there should be present enough elements to comprehensively manifest the derived distribution of normals. The amplitude of waveform is defined by profile segments' coalignment method and 3D model dimensions can be chosen freely but should be reasonable for production and exploitation.

## RESULTS OF VIRTUAL VALIDATION

To validate the reflection distribution of the modelled reference reflectance sample surface, a Monte-Carlo ray-tracing simulation was performed. Simulation parameters were kept close to the ones used for mesh-reinforced foil measurements. Reflection was modelled by Torrance-Sparrow model [2] with parameters corresponding to bare aluminium. The result of the simulation can be seen in Figure 4.

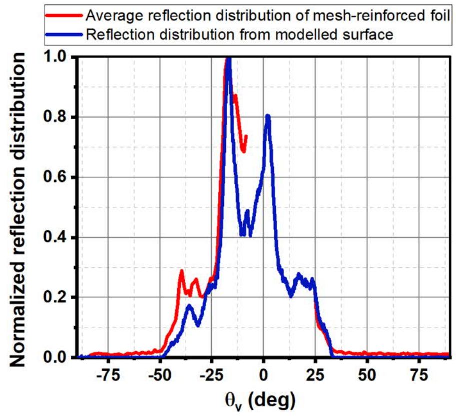


**Figure 4.** Reflection distribution of modelled surface obtained using Monte-Carlo simulation

The reflection distribution of the modelled surface is fairly close to the original average reflection distribution of the mesh-reinforced foil. The reflection maximum and the dispersion almost coincide and the overall shape is very similar.

The suitability of the modelled 3D surface to serve as a reference sample was also assessed. Virtual illumination beam was moved ±12 mm along the surface and areas under reflection distribution were compared. Area standard deviation was 4.4%. Decreasing wavelength, i.e. using $d_c = \bar{a}_b/4 = 1.93$ mm decreased standard deviation down to 0.65%.

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