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Soiling of building envelope surfaces and its effect on solar reflectance – Part III: Interlaboratory study of an accelerated aging method for roofing materials

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ABSTRACT

A laboratory method to simulate natural exposure of roofing materials has been reported in a companion article. In the current article, we describe the results of an international, nine-participant interlaboratory study (ILS) conducted in accordance with ASTM Standard E691-09 to establish the precision and reproducibility of this protocol. The accelerated soiling and weathering method was applied four times by each laboratory to replicate coupons of 12 products representing a wide variety of roofing categories (single-ply membrane, factory-applied coating (on metal), bare metal, field-applied coating, asphalt shingle, modified-bitumen cap sheet, clay tile, and concrete tile). Participants reported initial and laboratory-aged values of solar reflectance and thermal emittance. Measured solar reflectances were consistent within and across eight of the nine participating laboratories. Measured thermal emittances reported by six participants exhibited comparable consistency. For solar reflectance, the accelerated aging method is both repeatable and reproducible within an acceptable range of standard deviations: the repeatability standard deviation s_r ranged from 0.008 to 0.015 (relative standard deviation of 1.2–2.1%) and the reproducibility standard deviation s_R ranged

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from 0.022 to 0.036 (relative standard deviation of 3.2–5.8%). The ILS confirmed that the accelerated aging method can be reproduced by multiple independent laboratories with acceptable precision. This study supports the adoption of the accelerated aging practice to speed the evaluation and performance rating of new cool roofing materials.

1. Introduction

Highly reflective roofs can decrease the energy required for building air conditioning, help mitigate the urban heat island effect, and slow global warming [1–6]. However, these benefits are diminished by soiling and weathering processes that reduce the solar reflectance of most roofing materials [7–11]. Soiling results from the deposition of atmospheric particulate matter and the growth of microorganisms, both of which absorb sunlight. Weathering of materials occurs with exposure to water, sunlight, and temperature change [9].

This article describes an interlaboratory study (ILS) conducted to establish the precision and reproducibility of an accelerated aging method, developed by Lawrence Berkeley National Laboratory (LBNL), that mimics the changes to the solar reflectance and thermal emittance of roofing materials induced by natural exposure. It follows recent publication of two studies that (a) analyzed the initial and aged radiative properties of hundreds of products rated by the Cool Roof Rating Council (CRRC) and the Energy Star program of the U.S. Environmental Protection Agency (EPA) [8]; and (b) developed an accelerated aging method to simulate in the laboratory weathering and soiling processes in a much shorter time frame [7].

The accelerated aging method consists of three steps: (1) exposing a roofing product in a weathering apparatus before soiling, to provide UVA, moisture, and temperature conditioning; (2) spraying a waterborne soiling mixture that includes soot, organic matter, dusts, and salts; and (3) exposing the soiled coupon in the weathering apparatus to simulate the cleaning effects of rain and condensation. The method was applied to 26 products—single-ply membranes, factory-applied coatings (on metal), bare metal, field-applied coatings, clay tiles, concrete tiles, modified-bitumen cap sheets, and asphalt shingles—and shown to reproduce in three days the CRRC's three-year aged values of solar reflectance [7]. This practice was approved in March 2015 by ASTM International as D7897-15, "Standard Practice for Laboratory Soiling and Weathering of Roofing Materials to Simulate Effects of Natural Exposure on Solar Reflectance and Thermal Emittance" [12]. In April 2015, ASTM D7897-15 was adopted by the CRRC as an option for obtaining interim "aged" ratings for roofing products while they undergo three years of natural exposure [13].

In development of ASTM D7897-15, we followed an established ASTM practice to assess the consistency of the accelerated aging method. The results of the ILS, as well as feedback from the participating laboratories, are reported. A precision statement that includes the repeatability and reproducibility determined in this ILS was developed for incorporation into the ASTM draft standard. The adoption of the accelerated aging method as an ASTM practice should provide a useful tool for the roofing and weathering industries to speed development of high performance building envelope materials that resist soiling, maintain high solar reflectance, and save energy.

2. Theory

The ILS was designed and executed in accordance with ASTM E691-09, "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method" [14], which is substantively similar to the current version of this standard, ASTM E691-14 [15]. The ILS was led by LBNL. Data from the interlaboratory study were used to evaluate the method's consistency, and to estimate precision statistics (within-lab and between-lab variations).

Evaluation of consistency for measurements made on a given specimen—here, a roofing product—involve two statistics, k (within-laboratory) and h (between-laboratories). Let a 'cell' denote the set of n replicate measurements performed by one of p participants, and $x_{i,j}$ represent the value for replicate j measured by participant i. The within-laboratory consistency statistic k for participant i is the ratio of the cell standard deviation for participant i, s_i, to the repeatability standard deviation, s_r [15]. That is,

$$k_i \equiv \frac{s_i}{s_r}, \tag{1}$$

where

$$s_i \equiv \sqrt{\frac{\sum_{j=1}^{n} (x_{i,j} - \bar{x}_i)^2}{n-1}} \tag{2}$$

and

$$s_r \equiv \sqrt{\frac{\sum_{i=1}^{p} (s_i)^2}{p}}. \tag{3}$$

Here

$$\bar{x}_i \equiv \frac{\sum_{j=1}^{n} x_{i,j}}{n} \tag{4}$$

is the cell average for participant i. The k statistic compares variability within a laboratory to variability over all laboratories.

The between-laboratories consistency statistic h for participant i is the ratio of the cell deviation for participant i to the standard deviation of the cell averages for all participants. That is,

$$h_i \equiv \frac{\bar{x}_i - \bar{\bar{x}}}{s_{\bar{x}}} \tag{5}$$

where

$$\bar{\bar{x}} \equiv \frac{\sum_{i=1}^{p} \bar{x}_i}{p} \tag{6}$$

is the average of the cell averages, and

$$s_{\bar{x}} \equiv \sqrt{\frac{\sum_{i=1}^{p} (\bar{x}_i - \bar{\bar{x}})^2}{p-1}} \tag{7}$$

is the standard deviation of the cell averages. The h statistic can be used to evaluate the overall variability of the measurements among the participants, and to compare the results of one participant to those of all other participants.