CRRC-1 Method #1: Standard Practice for Measuring Solar Reflectance of a Flat, Opaque, and Heterogeneous Surface Using a Portable Solar Reflectometer

Scope

This standard practice covers a technique for estimating the mean solar reflectance of a flat, opaque, and heterogeneous test surface at standard conditions, such as a variegated, granule-covered asphalt roofing shingle. The mean solar reflectance of the test surface is determined by averaging the solar reflectances of randomly located spots (small regions) measured with a commercial portable solar reflectometer in accordance with ASTM C1549.

This standard practice must be used in conjunction with ASTM C1549.

This standard practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard practice to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

Reference Documents

ASTM Standards

C1549, Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer.

Terminology

Estimate of Sample Mean Standard Error. The sample (rather than population) standard deviation divided by the square root of the number of samples.

Heterogeneous. Consisting of dissimilar or diverse ingredients or constituents.

Population. The group of sample values about which conclusions are to be drawn, such as a set of solar reflectance values determined from nonoverlapping spots (small regions) that cover an entire test surface.

Population Mean. The arithmetic mean of the property values (e.g., solar reflectances) measured for all members of a population.

Population Standard Deviation. The square root of the arithmetic mean of the squares of the deviation from the population mean.

Reflectometer. A device that measures reflectance.

Sample Mean. The arithmetic mean of the property values (e.g., solar reflectances) measured for all members of a sample set.

Sample Mean Standard Error. The population standard deviation divided by the square root of the number of samples.

Sample Set. A subset of the population, such as a set of nonoverlapping spots (small regions) on a test surface.

Sample Standard Deviation. The square root of the ratio of the sum of the squares of the deviation from the sample mean to a number one less than the number of samples.

Spot. A small region of a test surface, such as a 1” x 1” square or a 1”-diameter circle, whose solar reflectance can be measured.

Test Surface. A flat, opaque, and heterogeneous surface, such as that of a variegated, granule-covered asphalt shingle.

Test Surface Mean Solar Reflectance. The ratio of solar energy reflected from a test surface to the solar energy incident on a test surface, equal to the ratio of area-integrated solar reflectance to area.

Variegated. Having discrete markings of different colors.

Summary of Standard Practice

For a flat, opaque, and heterogeneous test surface, solar reflectances are measured in accordance with ASTM C1549 at a series of randomly located, non-overlapping spots (small areas) until the sample mean standard error is small enough to use the sample mean as an estimate of the mean solar reflectance of the test surface. The algorithm for selecting measurement locations, computing the sample mean, and computing the sample mean standard error may be implemented with the assistance of software available from the Cool Roof Rating Council (CRRC).

Significance and Use

This standard practice provides a method for determining the mean solar reflectance of a flat, opaque, and heterogeneous surface, from multiple, random and non-duplicative spot measurements of solar reflectance.

Procedure

Set-up

1. Obtain a representative test specimen, as determined by CRRC 1.

2. Let w and h represent the width and height of the test surface in units of inches.

3. Place a pair of inch-marked rulers at a right angle on two sides of the test surface to establish a grid of $w \times h$ square cells, each 1" x 1" and centered on integer coordinates. If the area of the test surface does not exceed 30 square inches, apply Procedure A. If the area is 30 square inches in area or greater, apply Procedure B.

Procedure A (for test surfaces not exceeding 30 square inches in area)

1. Measure the solar reflectance at the center of each cell with a solar spectrum reflectometer in accordance with ASTM C1549, centered over each cell.

2. Report the mean value of cell solar reflectance as the mean solar reflectance of the test surface.

Procedure B (for test surfaces exceeding 30 square inches in area)

Note: Procedure B is implemented by software available from the CRRC.

1. Measure the solar reflectances at the centers of a minimum of 30 different and randomly selected cells with a solar spectrum reflectometer centered over each cell in accordance with ASTM C1549.

2. Compute the mean, standard deviation, and estimate of standard error of the solar reflectance of the sample set. These quantities are defined in Eqs. (3), (4), and (6) of the Appendix, respectively.

3. If the estimate of sample mean standard error exceeds 0.005, increase the number of samples by measuring solar reflectances of additional, different, and randomly selected cells.

4. Repeats steps 2 and 3 until the estimate of sample mean standard error of the sample set does not exceed 0.005.

5. Report the sample mean plus or minus twice the estimate of sample mean standard error as the mean solar reflectance to within 95% confidence.

Report

Include in the report, in addition to the requirements stated in ASTM C1549, the following:

Data Requirements

1. The width, height, and area of the test surface.

2. The solar reflectance measurement procedure followed (A or B).

3. The central coordinates and solar reflectance of each cell measured.

4. For Procedure A (applied to test surfaces not exceeding 30 square inches in area), the mean solar reflectance of the test surface, equal to the mean value of cell solar reflectance.

5. For Procedure B (applied to test surfaces exceeding 30 square inches in area), the mean solar reflectance of the test surface to within 95% confidence, expressed as the sample mean plus or minus twice the estimate of sample mean standard error.

Test Sample

1. Manufacturer of the product

2. Manufacturer-designated product name and color.

Date

Date sample was tested.

Precision and Bias

Procedure B was evaluated in a round robin test for six products (solar reflectance 0.04 - 0.20) by five laboratories (Table 1). For five of the six products, the spread in reported values (maximum – minimum) did not exceed 0.01. For the sixth product, the spread was 0.03.

Table 1 Precision and Bias

Sample Number	Sample	A	B	C	D	E	**Mean**
#2	Black 3 Tab	0.038	0.036	0.04	0.034	0.04	0.04
#3	Lt. Gray 3 Tab	0.201	0.19	0.20	0.174	0.19	0.19
#4	Contrast 3 Tab	0.070	0.068	0.07	0.064	0.073	0.07
#5	Brown Laminate	0.067	0.06	0.06	0.058	0.062	0.06
#6	Green Slate	0.060	0.055	0.06	0.049	0.059	0.06
#1	Brown Shake	0.060	0.061	0.06	0.053	0.069	0.06

Appendix

All reflectances in the following discussion are solar reflectances.

The mean reflectance

$$R \equiv A^{-1} \int_A r \, dA \qquad (1)$$

of a test surface of area A is equal to the mean reflectance of the entire population of $N = A/a$ surface "spots,"

$$\mu \equiv \frac{1}{N}\sum_{i=1}^{N} r_i \,. \tag{2}$$

Each spot i is a subregion of reflectance r_i and area a that is small enough to be measured with a reflectometer, and does not overlap any of its neighbors. If N is large, it is convenient to estimate the population mean spot reflectance μ, and hence the test surface mean reflectance R, of a large surface by randomly sampling a population subset. Consider a sample set of n different, non-overlapping, and randomly located spots that have mean reflectance

$$\bar{r} \equiv \frac{1}{n}\sum_{i=1}^{n} r_i \tag{3}$$

with standard deviation

$$s \equiv \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(r_i - \bar{r}_n\right)^2} \tag{4}$$

By the Central Limit theorem, the sample mean $\bar{r}$ has a standard error

$$\sigma_{\bar{r}} = \sigma / \sqrt{n} \tag{5}$$

where σ is the standard deviation of the spot reflectances of the entire population (Crow et al., 1960). The population mean spot reflectance μ (which is also the mean solar reflectance of the test surface, R) is equal to $\bar{r} \pm 2\sigma_{\bar{r}}$ (95% confidence). If the sample size n is sufficiently large (say, $n \geq 30$), the population standard deviation σ is well approximated by the sample standard deviation s, and the estimate of the sample mean standard error is

$$\sigma_{\bar{r}} \approx s / \sqrt{n} \tag{6}$$

The instrument used to measure spot reflectance in accordance with C1549 has a circular aperture. Hence, the test surface formed by a matrix of contiguous, non-overlapping circular measurement spots will cover a fraction $\pi/4 \approx 79\%$ of the rectangular region bounding the matrix of circles. The remaining 21% of the rectangular region will not be sampled. This should be acceptable if the optical properties of the area between each measurement circle and its bounding square are expected to be the same as those of the surface within each measurement circle.

Bibliography

Crow, E.L., F.A. Davis, and M.W. Maxfield. 1960. *Statistics Manual: With Examples Taken From Ordnance Development*. New York: Dover Publications.