Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer[1]

This standard is issued under the fixed designation C1549; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers a technique for determining the solar reflectance of flat opaque materials in a laboratory or in the field using a commercial portable solar reflectometer. The purpose of the test method is to provide solar reflectance data required to evaluate temperatures and heat flows across surfaces exposed to solar radiation.

1.2 This test method does not supplant Test Method E903 which measures solar reflectance over the wavelength range 250 to 2500 nm using integrating spheres. The portable solar reflectometer is calibrated using specimens of known solar reflectance to determine solar reflectance from measurements at four wavelengths in the solar spectrum: 380 nm, 500 nm, 650 nm, and 1220 nm. This technique is supported by comparison of reflectometer measurements with measurements obtained using Test Method E903. This test method is applicable to specimens of materials having both specular and diffuse optical properties. It is particularly suited to the measurement of the solar reflectance of opaque materials.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *This standard 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 to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E903 Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres

E1980 Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces

2.2 *ANSI/CRRC Standard:*[3]

ANSI/CRRC S100 Standard Test Methods for Determining Radiative Properties of Materials

3. Terminology

3.1 *Definitions*—For definitions of some terms used in the test method, refer to Terminology C168.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *air mass*—air mass is related to the path length of solar radiation through the Earth's atmosphere to the site of interest. Air mass 1 is for a path of normal solar radiation at the Earth's equator while air mass 2 indicates two times this path length.

3.2.2 *solar reflectance*—the fraction of incident solar radiation upon a surface that is reflected from the surface.

3.3 *Symbols:*

3.3.1 A—area normal to incident radiation, m^2.

3.3.2 Q_{abs}—rate at which radiant heat is absorbed per m^2 of area, W.

3.3.3 q_{solar}—solar flux, W/m^2.

3.3.4 r—solar reflectance, dimensionless.

4. Summary of Test Method

4.1 This test method employs a diffuse tungsten halogen lamp to illuminate a flat specimen for two seconds out of a ten-second measurement cycle. Reflected light is measured at an angle of 20° from the incident angle with four detectors. Each detector is equipped with color filters to tailor its electrical response to a range of wavelengths in the solar spectrum. Software in the instrument combines the outputs of the four detectors in appropriate proportions to approximate the response for incident solar radiation through air mass 0, 1, 1.5,

[1] This test method is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Cool Roof Rating Council (CRRC), 449 15th Street, Suite 400, Oakland, CA 94612, http://www.coolroofs.org.

or 2. The solar reflectance for the desired air mass is selectable from the instrument's keypad. The reflectances measured by the individual detectors are also available from the keypad and digital readout. The instrument is calibrated using a black body cavity for a reflectance of zero and one or more surfaces of known solar reflectance provided by the manufacturer. A surface to be evaluated is placed firmly against the 2.5 cm diameter opening on the measurement head and maintained in this position until constant readings are displayed by the digital readout. A comparison of techniques for measuring solar reflectance is available.[4]

5. Significance and Use

5.1 The temperatures of opaque surfaces exposed to solar radiation are generally higher than the adjacent air temperatures. In the case of roofs or walls enclosing conditioned spaces, increased inward heat flows result. In the case of equipment or storage containers exposed to the sun, increased operating temperatures usually result. The extent to which solar radiation affects surface temperatures depends on the solar reflectance of the exposed surface. A solar reflectance of 1.0 (100 % reflected) would mean no effect on surface temperature while a solar reflectance of 0 (none reflected, all absorbed) would result in the maximum effect. Coatings of specific solar reflectance are used to change the temperature of surfaces exposed to sunlight. Coatings and surface finishes are commonly specified in terms of solar reflectance. The initial (clean) solar reflectance must be maintained during the life of the coating or finish to have the expected thermal performance.

5.2 The test method provides a means for periodic testing of surfaces in the field or in the laboratory. Monitor changes in solar reflectance due to aging and exposure, or both, with this test method.

5.3 This test method is used to measure the solar reflectance of a flat opaque surface. The precision of the average of several measurements is usually governed by the variability of reflectances on the surface being tested.

5.4 Use the solar reflectance that is determined by this method to calculate the solar energy absorbed by an opaque surface as shown in Eq 1.

$$Q_{abs} = A \cdot q_{solar} \cdot (1 - r) \quad (1)$$

5.4.1 Combine the absorbed solar energy with conductive, convective and other radiative terms to construct a heat balance around an element or calculate a Solar Reflectance Index such as that discussed in Practice E1980.

6. Apparatus

6.1 This test method applies to solar reflectance tests conducted with a portable reflectometer. The instrument consists of three major parts.

6.1.1 *Measurement Head*—The measurement head contains a tungsten halogen lamp used as the radiation source, the filters used to tailor the reflected radiation to specific wavelength ranges, and detectors for each of the four wavelength ranges. A 2.5 cm diameter circular opening on the top of the measurement head serves as a port through which incident and reflected radiation are transmitted to and from the test surface.

6.1.2 *Connecting Cable*—A connecting cable, connects the measurement head to the readout module. The connecting cable transmits electrical signals from the four detectors to the readout module.

6.1.3 *Readout Module*—The readout module that is connected to the measurement head includes a keypad for controlling the functions of the software, software for interpreting the signals from the measurement head, and a digital readout for solar reflectivity or the display of input parameters or calibration information. The resolution of the digital readout is 0.001. Detailed instructions for use of the keypad to communicate with the software are provided by the manufacturer of the apparatus.

6.1.4 *Reference Standards*—The calibration of the solar reflectometer is accomplished with a black body cavity that is supplied by the manufacturer and at least one high-reflectance standard. The solar reflectance of the high-reflectance standard or standards are programmed into the software to facilitate calibration. The apparatus accommodates up to eight solar reflectance standards.

6.1.5 *Test Specimens*—Specimens to be tested for solar reflectance shall be relatively flat and shall have a minimum dimension greater than 2.5 cm in order for the specimen to completely cover the measurement head opening. Test specimens of sufficient size are placed on top of the measurement head. Position the measurement head against a surface for in-situ or large area solar reflectance measurements.

7. Procedure

7.1 *Set-up*—The instrument requires 110 volt AC power. Take into account necessary safety precautions when using the instrument outside of conditioned spaces. Before power is applied and the instrument is turned on, either end of the cable must be connected to the socket on the measurement head. The other end must be connected to the socket on the readout and control module. The instrument powers up, ready to estimate the total solar reflectance through air mass 2. The instrument is designed to provide solar reflectances for air mass values of 0, 1, 1.5, or 2.0. The instrument shall be calibrated after at least 30 min. of warm-up time to avoid drift from the calibration. Leaving the instrument on for extended periods of time with a cover over the measurement head opening does not cause damage.

7.2 *Calibration (gain)*—At the end of the warm-up period, check and adjust the zero and gain. A zero reflectance blackbody cavity and various high reflectance standard specimens are provided to check zero and gain. If the blackbody cavity covers the opening of the measurement head and a non-zero reading is noted, then depress calibration/zero key. The instrument detects the presence of the zero reflectance cavity and resets the output reflectance to zero.

7.2.1 The gain or calibration adjustment requires that the reflectance of a known standard be coded into the instrument.

[4] Petrie, T. W., Desjarlais, A. O., Robertson, R. H., and Parker, D. S., "Comparison of Techniques for In Situ Nondamaging Measurement of Solar Reflectances of Low-Slope Roof Membranes," *International Journal of Thermophysics*, Vol 22, No. 5 , 2001, pp. 1613-1628.

Three standards provided with the instrument are preprogrammed into the memory. Memory for five additional standards is provided. A selection key on the keypad allows the user to select which of eight standards will be used. If the desired standard covers the opening of the measurement head and its reflectance is not noted on the display, then depress the calibration/zero key should be depressed. When a calibration standard is in position over the measurement head opening and the calibration/zero key is depressed, the instrument automatically detects that a high reflectance object is in place and resets the output reflectance to the selected standard's preset value. Zero is very stable but is conveniently checked by using the blackbody cavity to cover the measurement head between tests. Repeat the gain or calibration adjustment described above every 30 min.

7.3 *Solar Reflectance Measurement*—A surface area of sufficient size to cover the 2.5 cm diameter circular port on top of the measurement head is required. The flat specimen is placed on top of the circular port and either held in place by hand or by a weight that will hold the specimen firmly against the rim of the port. Position the measurement head manually against a surface such as a roof or wall. It is important that the rim of the specimen port be in contact with the specimen around the entire circumference of the port. The escape of radiation between the rim of the specimen port and the specimen will result in inaccurate solar reflectance values.

7.3.1 A test specimen shall be maintained in the test position for at least three ten-second cycles or until a consistent reading is observed on the digital readout. The readout gives either solar reflectance or solar absorptance (one minus solar reflectance). In the event of a reading that fluctuates between two values the average of the two values shall be recorded.

7.4 *Evaluation of a Surface*—Quantify the variability of the solar reflectance with position on a test specimen by measuring solar reflectance at three or more locations on the surface. If a surface is cleaned before testing, then the surface shall be allowed to dry completely before the reflectance test is undertaken.

7.5 *Calculation*—The set of individual solar reflectance measurements for a test surface shall be averaged and reported. If the set contains three or more measurements, then the standard deviation of the measurement set shall be reported. In any event, all of the individual measurements for a test surface shall be recorded and reported.

8. Report

8.1 Include in the test report a physical description of the surface being reported and indicate if the surface has been cleaned prior to the test. The test report shall include a description of the specimen substrate in the case of coatings and the thickness of the coating. The source or location of the test specimen shall be reported.

8.2 Include in the test report the manufacturer of the product being tested. Include any information about the history or age of the material in the test report.

TABLE 1 Solar Reflectances (%) of Roofing Materials—Precision Statistics

Material	Average	S_r	S_R	r	R
A	5.79	0.10	0.15	0.29	0.43
B	13.85	0.06	0.17	0.17	0.48
C	28.93	0.17	0.72	0.47	2.01
D	35.57	0.15	0.23	0.41	0.65
E	49.53	0.12	0.46	0.34	1.27
F	76.00	0.14	0.51	0.38	1.42
G	84.69	0.21	0.43	0.59	1.21

8.3 The temperature and relative humidity of the room or environment in which the measurements were conducted shall be reported.

8.4 The measured solar reflectances, arithmetic average of the measured reflectances, and if appropriate, the standard deviation of the set of measurements shall be reported.

8.5 The air mass to be associated with the measured solar reflectance shall be reported.

8.6 The date of the test shall be reported.

8.7 A statement of compliance with this standard shall be part of the report. Any exceptions to the procedure shall be stated in the report.

8.8 An estimated uncertainty in the reported solar reflectance shall be part of the report.

9. Precision and Bias

9.1 *Precision*—Precision statistics for seven roofing materials that were determined by an interlaboratory study involving six laboratories are shown in Table 1. Each laboratory reported three replicates on the same specimen. The repeatability, S_r, and the reproducibility standard deviations, S_R, were calculated from the data using Practice E691. The 95 % repeatability, r, and the reproducibility, R, limits were calculated from the following expressions: 2.8 S_r and 2.8 S_R, respectively. The calculations for r and R were made before S_r and S_R were rounded to two significant figures.

9.2 *Bias*—Solar reflectance values at air mass 1.5 were obtained for the seven materials in Table 1 using Test Method E903. These measurements are used to assess the bias of Test Method C1549 from Test Method E903 which is shown in Table 2. The average bias (C1549 value – E903 value) is 1.9 % if the result for material "a" is excluded. The C1549 test method yields solar reflectance results at air mass 1.5 that are 0.019 (1.9 %) greater than those obtained with Test Method E903.

TABLE 2 Bias of Test Method C1549 for Solar Reflectance from Test Method E903

Material	E903	C1549	C1549 – E903
A	6.0	5.8	-0.2
B	13.0	13.9	0.9
C	26.0	28.9	2.9
D	34.0	35.6	1.6
E	47.0	49.5	2.5
F	74.0	76.0	2.0
G	83.0	84.7	1.7

10. Keywords

10.1 portable reflectometer; reflectometer; solar reflectance; solar reflectometer

APPENDIX

(Nonmandatory Information)

X1. TECHNIQUE FOR MEASURING SOLAR REFLECTANCE OF A FLAT, OPAQUE, AND HETEROGENEOUS SURFACE USING A PORTABLE SOLAR REFLECTOR

X1.1 **Scope**—This is a technique for measuring the mean solar reflectance of a flat, opaque, and heterogeneous surface such as a variegated, granule-covered asphalt roofing shingle at standard conditions. The mean solar reflectance of the surface is determined by averaging the solar reflectances of spots (small regions) measured with a commercial portable solar reflectometer built and operated in accordance with Test Method C1549. This technique does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. The results obtained using this appendix apply only to the material tested.

X1.2 Terminology

X1.2.1 *estimate of sample mean standard error*—the sample standard deviation divided by the square root of the number of elements in the sample.

X1.2.2 *heterogeneous*—consisting of dissimilar or diverse ingredients or constituents.

X1.2.3 *population*—the set of values about which conclusions are to be drawn, such as a set of solar reflectance values determined from non-overlapping spots that cover an entire test surface.

X1.2.4 *population mean*—the arithmetic mean of the property values (that is, solar reflectances) measured for all members of a population.

X1.2.5 *population standard deviation*—the square root of the arithmetic mean of the squares of the deviation from the population mean.

X1.2.6 *reflectometer*—a device that measures reflectance.

X1.2.7 *sample mean*—the arithmetic mean of the property values (that is, solar reflectances) measured for all members of a sample set.

X1.2.8 *sample mean standard error*—the population standard deviation divided by the square root of the number of samples.

X1.2.9 *sample set*—a subset of the population, such as a set of non-overlapping spots on a test surface.

X1.2.10 *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.

X1.2.11 *spot*—a small region of a test surface, such as a 25 by 25 mm square or a 25 mm diameter circle.

X1.2.12 *test surface*—a flat, opaque, and heterogeneous surface, for example, a variegated, granule-covered asphalt shingle.

X1.2.13 *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).

X1.2.14 *variegated*—having discrete markings of different colors.

X1.3 Summary of Technique

X1.3.1 For a flat, opaque, and heterogeneous test surface, solar reflectances shall be measured in accordance with Test Method C1549 at a series of randomly located, non-overlapping spots 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. An algorithm for selecting measurement locations, computing the sample mean, and computing the sample mean standard error is available from the Cool Roof Rating Council (CRRC) (see 2.2).

X1.4 Significance and Use

X1.4.1 This technique 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.

X1.5 Procedure

X1.5.1 *Set-up:*

X1.5.1.1 Obtain a representative test specimen, as defined by ANSI/CRRC S100.

X1.5.1.2 Let w and h represent the width and height of the test surface in mm.

X1.5.1.3 Place a pair of rulers at a right angle on two sides of the test Surface to establish a grid of square cells, each 25 by 25 mm and centered on integer coordinates. (A ruler marked in inches is convenient for this step.) If the area of the test surface does not exceed 0.019 m^2, then apply Procedure A. If the area is 0.019 m^2 or greater, then apply Procedure B.

X1.5.1.4 *Procedure A:*

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

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

X1.5.1.5 *Procedure B:*

(1) Measure the solar reflectances at the centers of a minimum of 30 different and randomly selected cells in accordance with Test Method 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 Equations in X1.5.2.

(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) Repeat (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.

X1.5.2 *Calculations:*

X1.5.2.1 All reflectances in the following discussion are solar reflectances.

The mean reflectance:

$$\bar{r} \equiv A^{-1}\int_A r\, dA \quad \text{(X1.1)}$$

of a test surface of area is equal to the mean reflectance of the entire population of surface "spots,"

$$\mu \equiv \frac{1}{n}\sum_{i=1}^{n} r_i \quad \text{(X1.2)}$$

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

$$\bar{r} \equiv \frac{1}{n}\sum_{i=1}^{n} r_i \quad \text{(X1.3)}$$

with standard deviation:

$$s \equiv \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(r_i - \bar{r}_n)^2} \quad \text{(X1.4)}$$

By the Central Limit theorem, the sample mean has a standard error:

$$\sigma_{\bar{r}} = \sigma/\sqrt{n} \quad \text{(X1.5)}$$

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

$$\sigma_{\bar{r}} \approx s/\sqrt{n} \quad \text{(X1.6)}$$

The instrument used to measure spot reflectance in accordance with Test Method C1549 has a circular aperture. Hence, the test surface formed by a matrix of contiguous, non-overlapping circular measurement spots will cover a fraction π/4 ≈ 0.79 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.

X1.6 Report

X1.6.1 Include the following in the report in addition to the requirements stated in Test Method C1549.

(1) The width, length, 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 0.019 m^2), 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 0.019 m^2 , the mean solar reflectance of the test surface to within 95% confidence, expressed as the sample mean plus or minus two times the estimate of sample mean standard error,

(6) Manufacturer of the product,

(7) Manufacturer-designated product name and color, and

(8) Date specimen was tested.

X1.7 Precision and Bias

X1.7.1 *Bias*—No statement concerning bias is made since there is no standard reference material for solar reflectance.

X1.7.2 Procedure B was evaluated in a round robin involving five laboratories and six products. A precision statement based on E691 is shown in Table X1.1. Precision characterized by the reproducibility standard deviations, SR, and the 95% reproducibility limits R have been determined. R values were calculated using 2.8 times S_R . Data needed for repeatability were not obtained.

X1.7.3 *Precision*—This precision statement is provisional since the data obtained do not meet the minimum requirements of E691.

TABLE X1.1 Solar Reflectance (%) for Six Materials

Material	Average Solar Reflectance	S_R	R
1	6.06	0.57	1.59
2	3.76	0.26	0.73
3	19.10	1.09	3.04
4	6.90	0.33	0.93
5	6.14	0.34	0.96
6	5.66	0.47	1.30