Designation: E2540 – 16

Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.5 Degree Observation Angle[1]

This standard is issued under the fixed designation E2540; 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 measurement of the retroreflective properties of sign materials such as traffic signs and symbols (vertical surfaces) using a portable retroreflectometer that can be used in the field. The portable retroreflectometer is a hand-held instrument with a defined standard geometry that can be placed in contact with sign material to measure the retroreflection in a standard geometry. The measurements can be compared to minimum requirements to determine the need for replacement. Entrance and observation angles specified in this test method are those used currently in the United States and may differ from the angles used elsewhere in the world.

1.2 This test method is intended to be used for the field measurement of traffic signs but may be used to measure the performance of materials before placing the sign in the field or before placing the sign material on the sign face.

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.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
E284 Terminology of Appearance
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E808 Practice for Describing Retroreflection
E809 Practice for Measuring Photometric Characteristics of Retroreflectors
E810 Test Method for Coefficient of Retroreflection of Retroreflective Sheeting Utilizing the Coplanar Geometry

3. Terminology

3.1 The terminology used in this test method generally agrees with that used in Terminology E284.

3.2 *Definitions*—The delimiting phrase "in retroreflection" applies to each of the following definitions when used outside the context of this or other retroreflection standards.

3.2.1 *annular geometry, n*—the portable instrument retroreflection collection method where the retroreflected lux is collected in an annulus 0.1 degrees wide centered on the illumination axis.

3.2.1.1 *Discussion*—The angle measured from the illumination axis to the circle which divides the annulus into equal areas corresponds to a specific observation angle.

3.2.2 *coefficient of retroreflection, R_A, n—of a plane retroreflecting surface*, the ratio of the coefficient of luminous intensity (R_I) of a plane retroreflecting surface to its area (A), expressed in candelas per lux per square metre ($cd \cdot lx^{-1} \cdot m^{-2}$).

3.2.3 *datum axis, n*—a designated half-line from the retroreflector center perpendicular to the retroreflector axis.

[1] This test method is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.10 on Retroreflection.

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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.

3.2.4 *entrance angle, β, n*—the angle between the illumination axis and the retroreflector axis.

3.2.5 *entrance half-plane, n*—the half plane that originates on the line of the illumination axis and contains the retroreflector axis.

3.2.6 *instrument standard, n*—working standard used to standardize the portable retroreflectometer.

3.2.7 *observation angle, α, n*—the angle between the illumination axis and the observation axis.

3.2.8 *observation half-plane, n*—the half plane that originates on the line of the illumination axis and contains the observation axis.

3.2.9 *orientation angle,* ω_s*, n*—the angle in a plane perpendicular to the retroreflector axis from the entrance half-plane to the datum axis, measured counter-clockwise from the viewpoint of the source.

3.2.10 *portable retroreflectometer, n*—a hand-held instrument that can be used in the field or in the laboratory for measurement of retroreflectance.

3.2.10.1 *Discussion*—In this test method, "portable retroreflectometer" refers to a hand-held instrument that can be placed in contact with sign material to measure the retroreflection in a standard geometry.

3.2.11 *presentation angle, γ, n*—the dihedral angle from the entrance half-plane to the observation half-plane, measured counter-clockwise from the viewpoint of the source.

3.2.12 *retroreflection, n*—a reflection in which the reflected rays are returned preferentially in directions close to the opposite of the direction of the incident rays, this property being maintained over wide variations of the direction of the incident rays.

3.2.13 *rotation angle, ε, n*—the angle in a plane perpendicular to the retroreflector axis from the observation half-plane to the datum axis, measured counter-clockwise from the viewpoint of the source.

3.3 Definitions of entrance angle components β_1 and β_2, as well as other geometrical terms undefined in this test method, may be found in Practice E808.

4. Summary of Test Method

4.1 This test method involves the use of commercial portable retroreflectometers for determining the retroreflectivity of highway signing materials.

4.2 The entrance angle shall be –4°.

4.3 The observation angle shall be 0.5°.

4.4 The portable retroreflectometer uses an instrument standard for standardization.

4.5 After standardization, the retroreflectometer is placed in contact with the sign to be tested, ensuring that only the desired portion of the sign is within the measurement area of the instrument.

4.6 The reading displayed by the retroreflectometer is recorded. The retroreflectometer is then moved to another position on the sign, and this value is recorded. A minimum of four readings shall be taken and averaged for each retroreflective color on the sign to be tested.

5. Significance and Use

5.1 Measurements made by this test method are related to the night time brightness of retroreflective traffic signs approximately facing the driver of a mid-sized automobile equipped with tungsten filament headlights at about 100 m distance.

5.2 Retroreflective material used on traffic signs degrades with time and requires periodic measurement to ensure that the performance of the retroflection provides adequate safety to the driver.

5.3 The quality of the sign as to material used, age, and wear pattern will have an effect on the coefficient of retroreflection. These conditions need to be observed and noted by the user.

5.4 This test method is not intended for use for the measurement of signs when the instrument entrance and observation angles differ from those specified herein.

6. Apparatus

6.1 *Portable Retroreflectometer*—The retroreflectometer shall be portable, with the capability of being placed at various locations on the signs. The retroreflectometer shall be constructed so that placement on the sign will preclude stray light (daylight) from entering the measurement area of the instrument and affecting the reading.

6.2 *Instrument Standard,* or standards of desired color(s) and material(s).

6.3 *Light Source Requirements:*

6.3.1 The projection optics shall be such that the illuminance at any point over the measurement area shall be within 10 % of the average illuminance.

6.3.2 The aperture angle of the source as determined from the center of the measurement area shall be not greater than 0.1°.

6.4 *Receiver Requirements:*

6.4.1 The receiver shall have sufficient sensitivity and range to accommodate coefficient of retroreflection values from 0.1 to 1999.9 $cd \cdot lx^{-1} \cdot m^{-2}$.

6.4.2 The combined spectral distribution of the light source and the spectral responsivity of the receiver shall match the combined spectral distribution of CIE Illuminant A and the V(λ) spectral luminous efficiency function according to the following criterion: For any choice of plano-parallel colored absorptive filter mounted in front of a white retroreflective sample, the ratio of the R_A measured with the filter to the R_A measured without the filter shall be within 10 % of the Illuminant A luminous transmittance of an air spaced pair of two such filters.

6.4.3 The instrument may be either an instrument with point geometry, a "point instrument," or an instrument with annular geometry, an "annular instrument," depending on the shape of the receiver aperture (see Fig. 1). Point and annular instruments make geometrically different measurements of R_A, which may produce values differing on the order of 10 %. Both measurements are valid for most purposes, but the user should learn the

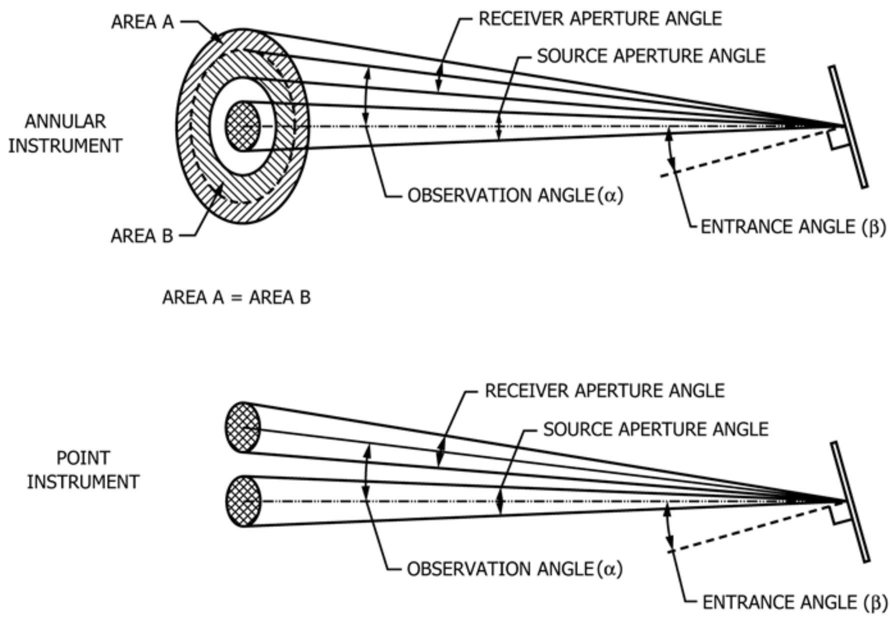
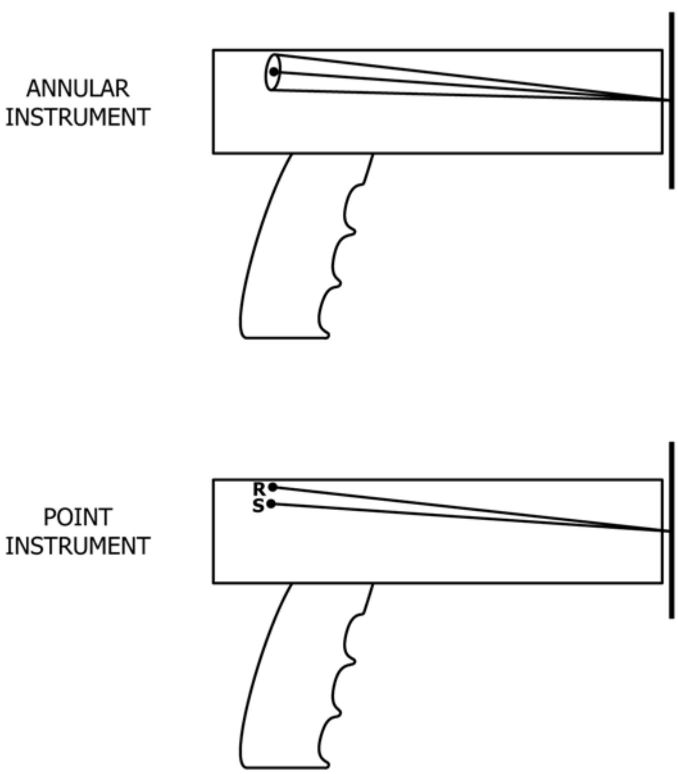


FIG. 1 Annular and Point Aperture Instrument Angles



NOTE 1—For each instrument type, the illumination beam is 4° downward. For the point instrument, receiver is above source.

FIG. 2 Upright Optical Schematics

type of instrument from its specifications sheet and be aware of certain differences in operation and interpretation. For both instrument types, the "up" position of the instrument shall be known. Both types of instruments may make additional measurements at observation angles other than the 0.5 degree of this specification and combine the measurement at two or more different observation angles if the readings at the different observation angles are reported separately.

6.4.3.1 The point instrument makes an R_A measurement with the source and receiver geometry virtually identical to an R_A measurement made on a range instrument following the procedure of Test Method E810. The 4° entrance angle would be set on a range instrument by setting β_1 =–4°; β_2 =0°. This may be called "–4° entrance angle." The rotation angle (ε) for the point instrument is determined by the angular position of the instrument on the sign face. Assuming the retroreflector's datum axis to be upward, the rotation angle equals 0° when the instrument is upright. Clockwise rotation of the instrument on the sign face increases the rotation angle.

6.4.3.2 For the point instrument the "up" marking shall be opposite the entrance half-plane. It shall be in the observation half-plane (see Fig. 2).

6.4.3.3 The annular instrument makes an R_A measurement similar to an average of a great number of R_A measurements on a range instrument with presentation angle (γ) varying between –180° and +180°. For the 4° entrance angle the range instrument would include the β_1 and β_2 settings indicated in Table 1. There is no definite rotation angle (ε) for the annular instrument. All values from –180° to +180° are included in the measurement.

6.4.3.4 For the annular instrument the "up" marking shall be opposite the entrance half-plane (see Fig. 2).

6.4.3.5 For both instrument types, the orientation angle (ω_s) is determined by the angular position of the instrument on the sign face. It is the rotation angle (ε) rather than the orientation angle (ω_s) which primarily affects retroreflection of signs measured at the small 4° entrance angle.

6.4.3.6 Rotationally insensitive sheetings, such as glass bead sheetings, have R_A values that are nearly independent of the rotation angle. Accordingly, the point and annular instruments will make practically identical measurements of R_A for signs made with such sheetings.

TABLE 1 Laboratory Emulation of Annular Instrument Geometry

α	β_1	β_2	ε
0.5°	3.86°	−1.03°	−165°
0.5°	3.47°	−2.00°	−150°
0.5°	2.83°	−2.83°	−135°
0.5°	2.00°	−3.46°	−120°
0.5°	1.04°	−3.86°	−105°
0.5°	0.00°	−4.00°	−90°
0.5°	−1.04°	−3.86°	−75°
0.5°	−2.00°	−3.46°	−60°
0.5°	−2.83°	−2.83°	−45°
0.5°	−3.47°	−2.00°	−30°
0.5°	−3.86°	−1.03°	−15°
0.5°	−4.00°	0.00°	0°
0.5°	−3.86°	1.03°	15°
0.5°	−3.47°	2.00°	30°
0.5°	−2.83°	2.83°	45°
0.5°	−2.00°	3.46°	60°
0.5°	−1.04°	3.86°	75°
0.5°	0.00°	4.00°	90°
0.5°	1.04°	3.86°	105°
0.5°	2.00°	3.46°	120°
0.5°	2.83°	2.83°	135°
0.5°	3.47°	2.00°	150°
0.5°	3.86°	1.03°	165°
0.5°	4.00°	0.00°	180°

6.4.3.7 Most prismatic retroreflectors are rotationally sensitive, having R_A values that vary significantly with rotation angle (ε), even at small entrance angles. The difference of R_A measurements made with the two types of instrument on prismatic signs may become as great as 20 % in extreme cases, but is generally on the order of 10 %. Neither the magnitude nor the direction of difference can be predicted for unknown samples. Thus, critical comparison of prismatic sign R_A values measured by instruments of the two types is not recommended.

6.4.3.8 A point instrument can gage the variation of R_A with rotation angle by placing it with different angular positions upon the sign face. R_A variation of 5 % for 5° rotation is not unusual. Accordingly, repeatable R_A measurement of prismatic signs with a point instrument, requires care in angular positioning.

6.4.3.9 An annular instrument cannot gage the variation of R_A with rotation angle. Accordingly, repeatable R_A measurement of prismatic signs with an annular instrument does not require care in angular positioning. Positioning to within ±15° is sufficient.

6.4.4 The aperture angle of the receiver as determined from the measurement area shall be not greater than 0.1°. The aperture angle of the receiver is measured from inner to outer ring limits for annular receivers (see Fig. 1).

6.4.5 The combined stability of the output of the light source and receiver shall not change more than ±1 % after 10 s when the retroreflectometer is in contact with the sign face.

6.4.6 The linearity of the retroreflectometer photometric scale over the range of readings expected shall be within 2 %. Correction factors may be used to ensure a linear response. A method for determining linearity can be found in Annex A2 of Practice E809.

6.5 *Measurement Geometry:*

6.5.1 The geometry used to determine the photometric performance shall be in accordance with Practice E808.

6.5.2 The light source and receiver shall be at optical infinity and possess an observation angle of 0.5 ± 0.01° (±36 arc seconds) as measured from the center of the source aperture to the centroid of responsivity of the receiver at all presentation angles. For annular receivers, the observation angle is taken as the angular distance when area A and area B are equal (see Fig. 1). The reason for this collimation requirement is to accommodate the correct measurement of large optical elements in the retroreflective sheeting as stated in 8.1.4.2 by maintaining a constant entrance angle over the sample area.

6.5.3 The entrance angle of the light source shall be –4 ± 1°.

7. Standardization

7.1 The retroreflectometer shall be standardized using an instrument standard consisting of a separate panel or disc of a material with a known R_A value. The calibration values shall be maintained by checking against other standards or by laboratory recalibration sufficiently often to ensure that no large uncertainties in the measurement can occur.

7.1.1 Instrument standards are generally of glass-bead sheeting construction. The glass-bead sheeting instrument standard shall be calibrated in the laboratory range instrument at α=0.5°; β_1=–4°; β_2=0°; ε=0°. The glass-bead sheeting standard must have a datum mark for the calibration laboratory, but this mark is not required for its use with either type of instrument.

7.1.2 If prismatic materials will be used as standards, they shall be calibrated differently for the two types of instrument.

7.1.2.1 A prismatic standard for a point instrument shall be calibrated following the procedure of Test Method E810. It shall be calibrated in the laboratory range instrument at α =0.5°; β_1=–4°; β_2=0°; ε=0°.

(a) The prismatic instrument standard must have a datum mark for the calibration laboratory, and this mark is required for its use with the point instrument. The datum mark shall align with the "up" direction of the instrument.

(b) A prismatic standard for an annular instrument shall be calibrated in the laboratory range instrument at the angles given in Table 1. The calibration involves twenty-four R_A measurements, which values are then averaged to produce the calibration R_A value for the instrument standard.

(c) The prismatic instrument standard must have a datum mark for the calibration laboratory, and this mark may be required for its use with the annular instrument. In this case, the datum mark shall align with the "up" direction of the instrument. The user shall determine by experimentation whether it is required. If the instrument's R_A measurements of the prismatic standard made at many rotations covering 360°, do not differ by more than 3 %, then the standard's datum mark may be ignored in use. Greater variation is consistent with the annular instrument's specified geometry.

8. Procedure

8.1 Use the manufacturer's instructions for operation of the retroreflectometer, which generally uses the following procedure:

8.1.1 Turn on the retroreflectometer and allow it to reach equilibrium.

8.1.2 Adjust the retroreflectometer for zero reading (0 ± 2 in the least significant digit) without the instrument standard using either a black material or an internal shutter.

8.1.3 Place the retroreflectometer against an appropriate instrument standard similar in color, material, and type to the sign material to be measured and having a known and relatively constant retroreflectivity. Adjust the standardization control to the value of the standard. Alternatively, a white standard shall be used and a correction factor shall be applied to the readings obtained by use of the white standard. To determine this correction factor, carry out the following steps:

8.1.3.1 Standardize the instrument using a white standard,

8.1.3.2 Without changing the instrument settings, note the reading for a selected prephotometered standard similar in color, material, and type to the sign material to be tested,

8.1.3.3 Obtain a correction factor by dividing the known retroreflectance of the selected prephotometered standard by the reading noted in 8.1.3.2, and

8.1.3.4 Multiply all reading obtained for sign material of a particular color, material, and type by the correction factor obtained for that color, material, and type.

8.1.4 Place the retroreflectometer in contact with the sign background's face, with the instrument's "up" direction aligned with the sign's "up" direction. Record the retroreflectometer readings in four different locations on the same sign. Record the readings and locations on the sign face where the measurements were made (see Fig. 3).

8.1.4.1 This test method does not require determining the rotation angle for the measurement. Determining the rotation angle requires identification of the retroreflector and its datum axis, subjects beyond the scope of this test method.

8.1.4.2 When measuring molded prismatic signs composed of optical elements having average diameter greater than 1 mm, it is preferable to use a standard of similar composition. If the standard used is composed of retroreflective sheeting, then the instrument readings shall be multiplied by the following correction factor:

$$1 + 0.9\frac{d}{D} \quad (1)$$

where:

d = average diameter of the sign's optical elements and
D = diameter of the instrument's measuring area.

FIG. 3 Portable Retroreflectometer Positioned for Photometry of Sign Face

8.1.4.3 When measuring signs mounted on translucent substrates, rear illumination of the sign must be blocked, unless the instrument manual states, or tests demonstrate, that the instrument is immune to this illumination.

8.1.5 Repeat the steps given in 8.1.4 for the legend, if it is retroreflective, using the appropriate instrument standard for standardization.

8.1.6 When measuring a traffic sign, if required, take a second set of readings after wiping or washing the sign, and record the readings.

9. Calculations

9.1 For each sign or sign material, average the four readings for each color, and compute the ratio between the legend R_A and background R_A if both are retroreflective. The units for R_A are in candelas per lux per square metre ($cd \cdot lx^{-1} \cdot m^{-2}$).

9.2 Dividing the R_A of the legend by the R_A of the background will determine the contrast ratio of the sign.

10. Report

10.1 Report the following information:

10.1.1 Test date.

10.1.2 Sign location or identification number, or both, and other sign identification information including color, type, and age. For sign material, the lot number, color, type, and date of manufacture.

10.1.3 Model and serial number of the instrument used.

10.1.4 Average of at least four readings expressed as candelas per lux per square metre for the background and the legend and, if required, their ratio (retroreflective material only). Indicate on a drawing of the sign where the measurements were made.

10.1.5 Remarks concerning overall conditions of the sign affecting the sign performance adversely, such as peeling, delamination, discoloration, bullet holes, dents, etc., if desirable.

10.1.6 A statement concerning whether an annular or point apertured retroreflectometer was used in the measurement.

10.1.7 Optional photograph or photologging of the sign.

11. Sources of Error

11.1 There are many factors that cause high variability when taking readings in the field.

11.2 Retroreflectometers with differing entrance angles or observation angles, or both, will yield different readings.

11.3 Slight changes in the location of the retroreflectometer on the sign may yield different readings.

11.4 Stray light entering the instrument when not placed properly against the sign face will cause higher readings than the true values.

11.5 Annular instruments will effectively average several R_A values; see Table 1. For materials exhibiting variation of R_A with rotation or presentation angles, the values from annular instruments may differ from those from point instruments.

12. Precision and Bias

12.1 The precision of this test method is based on an interlaboratory study of ASTM E2540, Standard Test Method for Measurement of Retroreflective Signs Using a Portable Retroreflectometer at a 0.5 Degree Observation Angle, conducted in 2012. A total of nine laboratories participated in this study, testing of 35 different retroreflective materials. Each "test result" reported represents an individual determination, and all participants were asked to report triplicate test results for each material tested. Practice E691 was followed for the design and analysis of the data. Supporting data pending being filed at ASTM International Headquarters..

12.1.1 Repeatability can be interpreted as maximum difference between two results, obtained under repeatability conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

12.1.1.1 Repeatability limits are listed in Table 2 and Table 3.

12.1.2 *Reproducibility (R)*—The difference between two single and independent results obtained by different operators applying the same test method in different laboratories using different apparatus on identical test material would, in the long run, in the normal and correct operation of the test method, exceed the following values only in one case in 20.

12.1.2.1 Reproducibility can be interpreted as maximum difference between two results, obtained under reproducibility conditions, that is accepted as plausible due to random causes under normal and correct operation of the test method.

12.1.2.2 Reproducibility limits are listed in Table 2 and Table 3.

12.1.3 The above terms (repeatability and reproducibility limit) are used as specified in Practice E177.

12.1.4 Any judgment in accordance with statements 12.1.1 and 12.1.2 would have an approximate 95 % probability of being correct.

12.2 *Bias*—No reference materials were tested as part of this study, therefore no statement on bias can be made at this time.

12.3 The precision statement was determined through statistical examination of 1416 test results, submitted by 9 laboratories, measuring 35 retroreflective samples.

12.4 To judge the equivalency of two test results, it is recommended to choose the material that is closest in characteristics to the test material.

13. Keywords

13.1 portable retroreflectometers; retroreflection

TABLE 2 Point Retro-reflectivity

Material	ASTM D4956 Material Type	Average[A] $\bar{X}$	Repeatability Standard Deviation Sr	Reproducibility Standard Deviation SR	Repeatability Limit r	Reproducibility Limit R	r as % of mean	R as % of mean
1–White	Type I	43.51	0.52	1.58	1.45	4.43	3.34	10.19
31–White	Type I	21.32	0.49	0.91	1.36	2.54	6.40	11.94
2–Yellow	Type I	29.54	0.27	0.35	0.76	0.98	2.58	3.30
30–Yellow	Type I	15.24	0.76	0.99	2.12	2.77	13.90	18.16
3–Red	Type I	14.32	0.15	0.94	0.42	2.62	2.92	18.29
4–Blue	Type I	2.65	0.08	0.74	0.24	2.06	8.92	77.81
29–Orange	Type I	18.61	0.46	1.31	1.29	3.67	6.92	19.72
5–White	Type III	126.50	0.79	1.74	2.21	4.86	1.75	3.84
6–White	Type III	106.66	1.62	2.01	4.53	5.63	4.25	5.28
7–Blue	Type III	7.61	0.28	1.18	0.80	3.31	10.45	43.49
8–Green	Type III	22.56	0.69	2.62	1.94	7.33	8.58	32.51
9–Red	Type III	23.98	0.50	2.06	1.39	5.78	5.82	24.11
32–Red	Type III	40.73	0.59	2.80	1.64	7.85	4.04	19.27
34–Brown	Type III	23.42	0.84	1.03	2.35	2.88	10.04	12.29
35–Yellow	Type III	28.76	3.66	4.42	10.25	12.39	38.31	46.29
10–White	Type IV	297.35	6.73	20.18	18.84	56.52	6.34	19.01
11–White	Type IV	387.02	21.14	33.11	59.19	92.72	15.29	23.96
12–White	Type V	290.01	7.57	16.63	21.18	46.56	7.30	16.05
13–Yellow	Type V	139.07	10.41	12.64	29.14	35.40	20.95	25.45
14–Red	Type V	44.39	2.02	5.82	5.66	16.30	12.74	36.71
15–White	Type VIII	233.82	3.35	14.62	9.39	40.93	4.02	17.51
16–Yellow	Type VIII	189.05	5.69	14.28	15.92	39.99	8.42	21.15
17–Blue	Type VIII	27.68	0.89	2.18	2.51	6.10	9.05	22.02
18–Green	Type VIII	39.18	0.96	1.98	2.68	5.55	6.83	14.17
19–Red	Type VIII	62.42	7.51	8.65	21.02	24.22	33.68	38.80
20–White	Type IX	331.12	6.10	15.42	17.09	43.19	5.16	13.04
21–Yellow	Type XI	509.23	6.51	24.39	18.21	68.28	3.58	13.41
22–Orange	Type XI	237.47	36.24	43.07	101.48	120.60	42.73	50.79
23–White	Type XI	565.52	30.03	52.41	84.08	146.74	14.87	25.95
24–Yellow	Type XI	436.17	14.04	32.14	39.32	89.98	9.02	20.63
25–Red	Type XI	147.65	3.06	14.06	8.56	39.36	5.80	26.66
26–Blue	Type XI	43.09	0.96	2.93	2.69	8.21	6.24	19.05
27–Green	Type XI	87.14	0.82	4.68	2.29	13.11	2.63	15.05
28–White	Type IX	324.28	29.34	36.62	82.17	102.52	25.34	31.62
33–Yellow	Type IX	96.05	9.92	12.28	27.78	34.38	28.93	35.79

[A] The average of the laboratories' calculated averages.

TABLE 3 Annular Retro-reflectivity

Material	ASTM D4956 Material Type	Average[A] $\bar{X}$	Repeatability Standard Deviation Sr	Reproducibility Standard Deviation SR	Repeatability Limit r	Reproducibility Limit R	r as % of mean	R as % of mean
1–White	Type I	41.03	0.62	0.76	1.75	2.13	4.26	5.20
31–White	Type I	19.96	0.31	1.24	0.87	3.48	4.36	17.45
2–Yellow	Type I	27.93	0.51	0.71	1.44	1.98	5.14	7.09
30–Yellow	Type I	13.90	0.58	0.81	1.62	2.28	11.65	16.39
3–Red	Type I	12.96	0.34	0.80	0.95	2.24	7.36	17.32
4–Blue	Type I	1.81	0.28	0.79	0.79	2.22	43.71	122.83
29–Orange	Type I	17.19	0.34	1.07	0.94	3.00	5.50	17.45
5–White	Type III	122.11	2.17	2.17	6.08	6.08	4.98	4.98
6–White	Type III	100.64	2.79	2.79	7.82	7.82	7.77	7.77
7–Blue	Type III	6.32	0.24	1.04	0.67	2.90	10.55	45.91
8–Green	Type III	19.72	0.55	0.63	1.55	1.76	7.84	8.95
9–Red	Type III	20.73	1.75	3.01	4.89	8.43	23.60	40.67
32–Red	Type III	38.51	0.71	1.22	2.00	3.40	5.19	8.84
34–Brown	Type III	21.88	0.42	0.93	1.19	2.60	5.42	11.90
35–Yellow	Type III	24.87	1.61	3.23	4.51	9.04	18.13	36.36
10–White	Type IV	250.56	7.06	7.06	19.78	19.78	7.89	7.89
11–White	Type IV	356.33	10.09	10.09	28.25	28.25	7.93	7.93
12–White	Type V	266.50	4.75	11.52	13.30	32.25	4.99	12.10
13–Yellow	Type V	125.22	1.99	6.70	5.56	18.76	4.44	14.98
14–Red	Type V	39.89	1.41	1.59	3.96	4.45	9.93	11.16
15–White	Type VII	249.44	9.18	10.89	25.70	30.50	10.30	12.23
16–Yellow	Type VII	192.00	14.54	15.08	40.72	42.22	12.21	21.99
17–Blue	Type VII	28.84	0.69	1.03	1.92	2.90	6.66	10.04
18–Green	Type VII	42.13	5.45	5.45	15.25	15.25	36.20	36.20
19–Red	Type VII	66.96	1.80	2.59	5.03	7.25	7.52	10.82
20–White	Type IX	329.06	22.43	24.17	62.80	67.68	19.08	20.57
21–Yellow	Type XI	424.67	7.11	7.74	19.91	21.68	4.69	5.10
22–Orange	Type XI	180.83	3.21	8.50	9.00	23.80	4.98	13.16
23–White	Type XI	452.67	10.58	10.58	29.62	29.62	6.54	6.54
24–Yellow	Type XI	389.61	10.74	13.08	30.07	36.63	7.72	9.40
25–Red	Type XI	120.28	2.48	6.93	6.95	19.42	5.78	16.14
26–Blue	Type XI	38.00	0.77	0.89	2.16	2.50	5.68	6.58
27–Green	Type XI	75.29	1.86	3.21	5.20	9.00	6.90	11.95
28–White	Type IX	296.39	7.08	7.61	19.83	21.30	6.69	7.19
33–Yellow	Type IX	89.92	14.61	15.97	40.90	44.72	45.48	49.74

[A] The average of the laboratories' calculated averages.