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.

Designation: D4956 – 19

Standard Specification for Retroreflective Sheeting for Traffic Control[1]

This standard is issued under the fixed designation D4956; 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.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope

1.1 This specification covers flexible, non-exposed glass-bead lens and microprismatic, retroreflective sheeting designed for use on traffic control signs, delineators, barricades, and other devices. This specification does not address inks, overlays, or other imaging methods that may be applied to retroreflective sheeting material to create traffic signs or other devices.

1.2 Although this specification provides photometric requirements for retroreflective sheeting under evaluation, minimum performance requirements of in-service signs or other devices are outside the scope of this document.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 The following safety hazards caveat pertains only to the test methods portion, Section 7, of this specification. *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, health, and environmental 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]

B209 Specification for Aluminum and Aluminum-Alloy Sheet and Plate

B209M Specification for Aluminum and Aluminum-Alloy Sheet and Plate (Metric)

B449 Specification for Chromates on Aluminum

D2794 Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)

E284 Terminology of Appearance

E308 Practice for Computing the Colors of Objects by Using the CIE System

E808 Practice for Describing Retroreflection

E810 Test Method for Coefficient of Retroreflection of Retroreflective Sheeting Utilizing the Coplanar Geometry

E811 Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions

E991 Practice for Color Measurement of Fluorescent Specimens Using the One-Monochromator Method

E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation

E1247 Practice for Detecting Fluorescence in Object-Color Specimens by Spectrophotometry

E1347 Test Method for Color and Color-Difference Measurement by Tristimulus Colorimetry

E1349 Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional (45°:0° or 0°:45°) Geometry

E2152 Practice for Computing the Colors of Fluorescent Objects from Bispectral Photometric Data

E2153 Practice for Obtaining Bispectral Photometric Data for Evaluation of Fluorescent Color

E2301 Test Method for Daytime Colorimetric Properties of Fluorescent Retroreflective Sheeting and Marking Materials for High Visibility Traffic Control and Personal Safety Applications Using 45°:Normal Geometry

E3165 Test Method for Nighttime Retroreflected Chromaticity of Retroreflective Sheeting

G7/G7M Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials

G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials

G147 Practice for Conditioning and Handling of Nonmetallic Materials for Natural and Artificial Weathering Tests

[1] This specification is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.38 on Highway Traffic Control Materials.

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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.

G151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources
G155 Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

2.2 *Other Standards:*
ISO 4892-2:2006 Plastics—Methods of Exposure to Laboratory Light Sources—Part 2: Xenon-Arc Lamps[3]
ISO 4892-2:2006/Amd.1:2009 Plastics—Methods of Exposure to Laboratory Light Sources—Part 2: Xenon-Arc Lamps[3]
EN 12899-1:2007 Fixed, Vertical Road Traffic Signs—Part 1: Fixed Signs[4]

3. Terminology

3.1 *Definitions*—Definitions of terms are as described in Terminology E284, Practice E808, and Terminology G113.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *reboundable sheeting, n*—retroreflective material intended to be attached to flexible, impact-resistant plastic devices, such as traffic drum-like channelizing devices.

4. Classification

4.1 Retroreflective sheeting shall consist of a white or colored sheeting having a smooth outer surface and that essentially has the property of a retroreflector over its entire surface. There are nine types and five classes of retroreflective sheeting. Types are determined by conformance to the retroreflectance, color, and durability requirements listed in 6.1 and may be of any construction providing that those requirements are met. Type designation is provided as a means for differentiating functional performance. Typical examples of applications are provided for descriptive information only and are not intended to be limitations or recommendations. Common identifiers for each type are listed in 4.2.

4.1.1 The typical applications for the retroreflective sheeting addressed in this specification are:

Type	Typical Application
I	Highway signing, construction-zone devices, and delineators
II	Highway signing, construction-zone devices, and delineators
III	Highway signing, construction-zone devices, and delineators
IV	Highway signing, construction-zone devices, and delineators
V	Delineators
VI	Temporary roll-up signs, warning signs, traffic cone collars, and post bands
VII	This type designation has been replaced with Type VIII
VIII	Highway signing, construction-zone devices, and delineators
IX	Highway signing, construction-zone devices, and delineators
X	This type designation has been replaced with Type VIII
XI	Highway signing, construction-zone devices, and delineators

4.2 Retroreflective sheeting shall be classified as follows (the type sequence is not indicative of performance level):

4.2.1 *Type I*—A retroreflective sheeting referred to as "engineering grade" that is typically an enclosed lens glass-bead retroreflective material or a microprismatic retroreflective element material. Applications for this material include permanent highway signing, construction zone devices, and delineators.

4.2.2 *Type II*—A retroreflective sheeting referred to as "super engineer grade" that is typically an enclosed lens glass-bead retroreflective material or a microprismatic retroreflective element material. Applications for this material include permanent highway signing, construction zone devices, and delineators.

4.2.3 *Type III*—A retroreflective sheeting referred to as "high-intensity" that is typically manufactured as an encapsulated glass-bead retroreflective material or as a microprismatic retroreflective element material. Applications for this material include permanent highway signing, construction zone devices, and delineators.

4.2.4 *Type IV*—A retroreflective sheeting referred to as "high-intensity" that is typically an unmetalized microprismatic retroreflective element material. Applications for this material include permanent highway signing, construction zone devices, and delineators.

4.2.5 *Type V*—A retroreflective sheeting referred to as "super high-intensity" that is typically a metalized microprismatic retroreflective element material. This sheeting is typically used for delineators.

4.2.6 *Type VI*—An elastomeric retroreflective sheeting without adhesive. This sheeting is typically a vinyl microprismatic retroreflective material. Applications include orange temporary roll-up warning signs, traffic cone collars, and post bands.

4.2.7 *Type VII*—The use of a designation as Type VII has been discontinued.

4.2.8 *Type VIII*—A retroreflective sheeting typically manufactured as an unmetalized cube corner microprismatic retroreflective element material. Applications for this material include permanent highway signing, construction zone devices, and delineators.

4.2.9 *Type IX*—A retroreflective sheeting typically manufactured as an unmetalized cube corner microprismatic retroreflective element material. Applications for this material include permanent highway signing, construction zone devices, and delineators.

4.2.10 *Type X*—The use of a designation as Type X has been discontinued.

4.2.11 *Type XI*—A retroreflective sheeting typically manufactured as an unmetalized cube corner microprismatic retroreflective element material. Applications for this material include permanent highway signing, construction zone devices, and delineators.

NOTE 1—All retroreflective sheetings, but especially microprismatic sheetings, may have unique performance characteristics outside of the range of the standard geometries presented in the tables that define the types. Certain applications may require the use of a particular product within a particular type in order to achieve a desired level of retroreflectivity in a given situation. In these cases, information concerning additional performance characteristics must be obtained.

4.3 *Backing Classes*—The backing required for retroreflective sheeting shall be classified as follows:

4.3.1 *Class 1*—The adhesive backing shall be pressure sensitive, require no heat, solvent, or other preparation for adhesion to smooth, clean surfaces.

[3] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[4] Available from European Committee for Standardization (CEN), Avenue Marnix 17, B-1000, Brussels, Belgium, http://www.cen.eu.

4.3.2 *Class 2*—The adhesive backing shall have an adhesive that shall be activated by applying heat and pressure to the material. The temperature necessary to form a durable permanent bond shall be a minimum of 150 °F (66 °C).

4.3.2.1 The Class 2 material shall be repositionable under normal shop conditions and at substrate temperatures up to 100 °F (38 °C) and without damage to the material. The Class 2 material may be perforated to facilitate removal of air in heat-vacuum laminators, but the perforations must be of a size and frequency such that they do not cause objectionable blemishes when the sheeting is printed.

4.3.3 *Class 3*—The adhesive backing shall have a positionable, low-tack, pressure-sensitive adhesive that requires no heat, solvent, or other preparation for adhesion to smooth, clean surfaces. It shall be repositionable up to a temperature of 100 °F (38 °C) without damage to the material.

4.3.4 *Class 4*—The adhesive backing shall have a low-temperature, pressure-sensitive adhesive that permits sheeting applications at temperatures down to +20 °F (–7 °C) without the aid of heat, solvent, or other preparation for adhesion to smooth, dry, clean surfaces.

4.3.5 *Class 5*—This shall be a nonadhesive backing made of material commercially used for self-supporting products such as traffic cone collars, temporary roll-up warning signs, and post bands.

5. Ordering Information

5.1 The purchaser using this specification shall include the following information:

5.1.1 ASTM designation (D4956),

5.1.2 Classification type (see Section 4),

5.1.3 Adhesive class (see 4.3),

5.1.4 Daytime color (see 6.3),

5.1.5 Length and width of sheets (see 8.1),

5.1.6 Length and width of rolls (see 8.2),

5.1.7 Supplementary information, if required by the purchaser, including:

5.1.7.1 Compliance with the minimum coefficient of retroreflection for 0.1° observation angle is a supplementary requirement which shall apply only when specified. An observation angle of 0.1° may be specified where the long-distance performance of a sheeting is to be a requirement,

5.1.7.2 Fungus-resistance testing requirements (see Supplementary Requirement S1), and

5.1.7.3 Reboundable sheeting requirements (see Supplementary Requirement S2),

5.1.8 Indication that the sheeting is intended for work zone use, if applicable, to determine which weathering requirements apply, and

5.1.9 Any additional information.

6. Performance Requirements

6.1 This is a summary of the minimum performance requirements for each type of retroreflective sheeting.

NOTE 2—The 0.1° observation angle supplementary R_A requirements previously listed in this section have been moved to Appendix X3 to highlight their optional nature.

6.1.1 *Type I*—Minimum Coefficient of Retroreflection—Table 1; Outdoor Weathering—24 months, see 6.4; Daytime Luminance Factor—Table 2; Other requirements: When sheeting is specified for construction work zone applications, the outdoor weathering shall be twelve months.

6.1.2 *Type II*—Minimum Coefficient of Retroreflection—Table 3; Outdoor Weathering—36 months, see 6.4; Daytime Luminance Factor—Table 2; Other requirements: When sheeting is specified for construction work zone applications, the outdoor weathering shall be twelve months.

6.1.3 *Type III*—Minimum Coefficient of Retroreflection—Table 4; Outdoor Weathering—36 months, see 6.4; Daytime Luminance Factor—Table 2; Other requirements: When sheeting is specified for construction work zone applications, the outdoor weathering shall be twelve months.

6.1.4 *Type IV*—Minimum Coefficient of Retroreflection—Table 5; Outdoor Weathering—36 months, see 6.4; Daytime Luminance Factor—Table 2; Other requirements: When sheeting is specified for construction work zone applications, the outdoor weathering shall be twelve months.

6.1.5 *Type V*—Minimum Coefficient of Retroreflection—Table 6; Outdoor Weathering—36 months, see 6.4; Daytime Luminance Factor—Table 2; Other requirements: When sheeting is specified for construction work zone applications, the outdoor weathering shall be twelve months.

6.1.6 *Type VI*—Minimum Coefficient of Retroreflection—Table 7; Outdoor Weathering—six months, see 6.4; Daytime Luminance Factor—Table 2.

6.1.7 *Type VII*—Retroreflective sheeting materials previously classified as Type VII have been reclassified as Type VIII.

6.1.8 *Type VIII*—Minimum Coefficient of Retroreflection—Table 8; Outdoor Weathering—36 months, see 6.4; Daytime Luminance Factor—Table 2; Other requirements: When sheeting is specified for construction work zone applications, the outdoor weathering shall be twelve months.

6.1.9 *Type IX*—Minimum Coefficient of Retroreflection—Table 9; Outdoor Weathering—36 months, see 6.4; Daytime Luminance Factor—Table 2; Other requirements: When sheeting is specified for construction work zone applications, the outdoor weathering shall be twelve months.

6.1.10 *Type X*—Retroreflective sheeting materials previously classified as Type X have been reclassified as Type VIII.

6.1.11 *Type XI*—Minimum Coefficient of Retroreflection—Table 10; Outdoor Weathering—36 months, see 6.4; Daytime Luminance Factor—Table 2; Other requirements: When sheeting is specified for construction work zone applications, the outdoor weathering shall be twelve months.

TABLE 1 Type I Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Brown
0.2°	–4°	70	50	25	9.0	14	4.0	1.0
0.2°	+30°	30	22	7.0	3.5	6.0	1.7	0.3
0.5°	–4°	30	25	13	4.5	7.5	2.0	0.3
0.5°	+30°	15	13	4.0	2.2	3.0	0.8	0.2

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft² (cd·lx^{-1}·m^{-2}).

TABLE 2 Daytime Luminance Factor (*Y* %)[A]

Color	All except Type V		Type V	
	Minimum	Maximum	Minimum	Maximum
White	27	...	15	
Yellow	15	45	12	30
Orange	10	30	7.0	25
Green	3.0	12	2.5	11
Red	2.5	15	2.5	11
Blue	1.0	10	1.0	10
Purple	2.0	10	2.0	10
Brown	1.0	9.0	1.0	9.0
Fluorescent Yellow-Green	60			
Fluorescent Yellow	40			
Fluorescent Orange	20			
Fluorescent Pink	25	...		

[A] The luminance factors shown for fluorescent colors consist of the sum of a reflectance luminance factor and fluorescence luminance factor. The luminance factor may be determined using a good approximation to Illuminant D65, requiring an instrument with an appropriately filtered light source, or by using a bispectral photometer conforming to Practice E2153.

TABLE 3 Type II Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Brown
0.2°	–4°	140	100	60	30	30	10	5.0
0.2°	+30°	60	36	22	10	12	4.0	2.0
0.5°	–4°	50	33	20	9.0	10	3.0	2.0
0.5°	+30°	28	20	12	6.0	6.0	2.0	1.0

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE 4 Type III Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Brown
0.2°	–4°	250	170	100	45	45	20	12
0.2°	+30°	150	100	60	25	25	11	8.5
0.5°	–4°	95	62	30	15	15	7.5	5.0
0.5°	+30°	65	45	25	10	10	5.0	3.5

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

6.2 *Coefficient of Retroreflection*—The coefficient of retroreflection shall meet or exceed the minimum requirements for the appropriate type of sheeting (see Table 1 and Tables 3-10) as specified in 7.3.

6.3 *Daytime Color*—The color of the sheeting shall conform to requirements of Table 2 and Table 11 when tested in accordance with 7.4. Daytime color requirements were developed for a limited set of retroreflective sheetings and a limited set of measurement devices. Measurement techniques appropriate for a wider range of optical technologies and instruments are under development. Some sheeting may require visual assessment to determine the acceptability of daytime appearance.

6.4 *Accelerated Outdoor Weathering Requirements*—The retroreflective sheeting shall be weather resistant and show no appreciable cracking, scaling, pitting, blistering, edge lifting, or curling, or more than 1/32-in. (0.8-mm) shrinkage or expansion when tested in accordance with 7.6. Conduct retroreflectivity measurements after outdoor weathering at 0.2° observation and –4° and +30° entrance angles. The minimum coefficient of retroreflection (R_A) after weathering is specified in Table 12.

NOTE 3—Supplementary Requirement S3 describes a method for artificial accelerated weathering, which users of this specification may employ for preliminary judgment until outdoor weathering results are available.

6.5 *Colorfastness*—After the specified outdoor weathering, the specimen shall conform to the requirements of Table 2 and Table 11 when tested in accordance with 7.4 and 7.7.

6.6 *Shrinkage*—The retroreflective sheeting shall not shrink in any dimension more than 1/32 in. (0.8 mm) in 10 min or more than 1/8 in. (3.2 mm) in 24 h when tested in accordance with 7.8.

6.7 *Flexibility*—The sheeting shall be sufficiently flexible to show no cracking when tested in accordance with 7.9.

6.8 *Liner Removal*—The liner, when provided, shall be easily removed without soaking in water or other solutions, and shall not break, tear, or remove adhesive from the sheeting. (See 7.10.)

6.9 *Adhesion*—When tested in accordance with 7.5, the adhesive backing of the retroreflective sheeting shall produce a bond that will support a 1¾-lb (0.79-kg) weight for adhesive classes 1, 2, and 3 or a 1-lb (0.45-kg) weight for adhesive class 4 for 5 min, without the bond peeling for a distance of more than 2 in. (51 mm).

6.10 *Impact Resistance*—Retroreflective sheeting shall show no cracking or delamination outside of the actual area of impact when subjected to the impact test in accordance with 7.11.

6.11 *Nighttime Color*—The nighttime color of the sheeting shall conform to the requirements of Table 13, when tested in accordance with 7.12.

7. Test Methods

7.1 *Test Conditions*—Unless otherwise specified in this specification, condition all adhesively bonded and unbonded test samples and specimens at a temperature of 73 ± 3 °F (23 ± 2 °C) and 50 ± 5 % relative humidity for 24 h prior to testing.

7.2 *Panel Preparations*—Unless otherwise specified in this specification, when tests are to be performed using test panels, apply the specimens of retroreflective material to smooth aluminum cut from Alloy 6061-T6 or 5052-H38, in accordance with Specification B209 or B209M. The sheets shall be 0.020 in. (0.508 mm), 0.040 in. (1.016 mm), or 0.063 in. (1.600 mm) in thickness, and a minimum of 8 by 8 in. (200 by 200 mm). Prepare the aluminum in accordance with Specification B449, Class 2, or degrease and lightly acid etch before the specimens are applied. Apply the specimens to the panels in accordance with the recommendations of the retroreflective sheeting manufacturer.

7.3 *Coefficient of Retroreflection:*

7.3.1 For lots, rolls, or sheets of retroreflective sheeting at least 1 yd long in new (unexposed) condition, take three samples in accordance with 9.1. Determine the coefficients of retroreflection in accordance with Test Method E810.

7.3.1.1 To conform to this specification, the average of the three coefficients of retroreflection shall meet the minimum

TABLE 5 Type IV Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Brown	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange
0.20°	–4°	360	270	145	50	65	30	14	18	290	220	105
0.20°	+30°	170	135	68	25	30	14	6.8	8.5	135	100	50
0.50°	–4°	150	110	60	21	27	13	6.0	7.5	120	90	45
0.50°	+30°	72	54	28	10	13	6	2.9	3.5	55	40	22

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE 6 Type V Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple
0.20°	–4°	700	470	280	120	120	56	28
0.20°	+30°	400	270	160	72	72	32	16
0.50°	–4°	160	110	64	28	28	13	6.4
0.50°	+30°	75	51	30	13	13	6.0	3.0

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

limits given in 6.2 and none of the coefficients of retroreflection obtained on any of the samples shall be less than 80 % of the values required in 6.2.

7.4 *Daytime Color:*

7.4.1 Determine the chromaticity and luminance factor *Y* (%) for CIE standard illuminant D65 and the 1931 CIE 2° standard observer in accordance with Practice E308, Test Methods E1347, E1349, and E2301, and Practices E991, E1164, E2152, and E2153, as applicable. The luminance factor is the sum of the reflectance luminance factor and the fluorescence luminance factor. Bispectral measurement provides the individual factors, while measurement with simulated D65 provides their sum.

7.4.1.1 For fluorescent specimens, it is necessary either that the physical illumination of the specimen be a good approximation to illuminant D65, requiring an instrument with an appropriately filtered light source, or else that a bispectral photometer conforming to Test Method E2301 be used. The presence of fluorescence may be determined through use of Practice E1247.

7.4.2 There are three types of 45/0 (0/45) instruments: annular, circumferential, and uniplanar (see Fig. 1). Measurement of prismatic sheeting with circumferential instruments may require multiple measurements. Measurement of prismatic sheeting with uniplanar instruments definitely requires multiple measurements.

7.4.2.1 If the measurement geometry is circumferential, then the testing laboratory must verify that the apertures in the ring are sufficiently close for acceptable approximation to an annular measurement. This may depend on the optical construction of the specimen, and must be determined by the testing laboratory. Multiple measurements of the same specimen area at different rotations may be averaged to improve the approximation to an annular measurement.

7.4.2.2 If the measurement geometry is uniplanar, then a sequence of measurements shall be made on the same specimen area at incremental rotations, and the measurement values shall be taken as averages over all the rotations. The number of rotations shall be large enough for acceptable approximation to an annular measurement. The number depends on the optical construction of the specimen and must be determined by the testing laboratory.

7.4.3 Instruments (spectrophotometers, colorimeters) used to measure daytime color shall have 45/0 or 0/45 illumination and viewing geometry. The referee instrument shall have 10° apertures for both illumination and viewing. Use of aperture sizes deviating from these may affect the measurement results.

7.5 *Adhesion*—Apply the sheeting to a test panel, 0.040 in. (1.016 mm) minimum thickness, prepared as specified in 7.2. Bond 4 in. (102 mm) of a 1 by 6-in. (25.4 by 152-mm) specimen to a test panel. Condition (see 7.1) and then attach the weight to the free end and allow it to hang free at an angle of 90° to the panel surface for 5 min.

7.6 *Outdoor Weathering*—Conduct outdoor exposures in accordance with Practice G7/G7M. During exposure, test panels shall be open backed and oriented at an angle of 45° from the horizontal and facing the equator in accordance with Practice G7/G7M. Expose two panels per location for the number of months specified in Table 12. Conduct exposures in locations with the climate types shown in Table 14. Panel labeling, and conditioning and handling of panels prior to exposure and during evaluation periods shall be in accordance with Practice G147.

7.6.1 *Specimen Mounting for Type VI Sheetings*—Clamp the ends of 4 by 12-in. (100 by 300-mm) specimens between 1 by 8 by 5⁄64-in. (25 by 200 by 2-mm) 6061-T6 aluminum bars, and attach these bars to mounting strips on the outdoor exposure rack. Expose the specimens so that the long axis is parallel to the ground so that bolts used to clamp specimen ends do not interfere with attachment to the test rack. Fig. 2 is a diagram showing the arrangement of the clamping bars and the test specimen.

7.6.2 *Washing Panels After Exposure*—Following exposure, gently wash the panels using a soft cloth or sponge and clean water or a dilute solution of a mild detergent (1 % by weight in water, maximum concentration). After washing, rinse thoroughly with clean water, and blot dry with a soft, clean cloth. After washing and drying, condition the panels at room temperature for at least 2 h prior to conducting any property measurements.

7.6.3 *Measurement of Coefficient of Retroreflection*—After panels have been washed, dried, and conditioned in accordance with 7.6.2, measure retroreflectance at 0.2° observation and –4° and 30° entrance angles. Report the average of the coefficient of retroreflection measured at each geometry on the two panels from each exposure location.

NOTE 4—The use of two samples per weathering deck is considered a minimum and reflects historical practice and practicality. Additional

TABLE 7 Type VI Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange	Fluorescent Pink
0.20°	–4°	500	350	125	60	70	45	20	400	300	200	150
0.20°	+30°	200	140	50	24	28	18	8.0	160	120	80	60
0.50°	–4°	225	160	56	27	32	20	9.0	180	135	90	65
0.50°	+30°	85	60	21	10	12	7.7	3.4	68	51	34	25

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE 8 Type VIII Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Brown	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange
0.20°	–4°	700	525	265	70	105	32	28	21	560	420	210
0.20°	+30°	325	245	120	33	49	15	13	10	260	200	95
0.50°	–4°	250	190	94	25	38	11	10	7.5	200	150	75
0.50°	+30°	115	86	43	12	17	5.0	4.6	3.5	92	69	35

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE 9 Type IX Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange
0.20°	– 4°	380	285	145	38	76	17	15	300	230	115
0.20°	+30°	215	162	82	22	43	10	8.6	170	130	65
0.50°	–4°	240	180	90	24	48	11	10	190	145	72
0.50°	+30°	135	100	50	14	27	6.0	5.4	110	81	41
1.00°	–4°	80	60	30	8.0	16	3.6	3.2	64	48	24
1.00°	+30°	45	34	17	4.5	9.0	2.0	1.8	36	27	14

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE 10 Type XI Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Brown	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange
0.20°	–4°	580	435	200	58	87	26	23	17	460	350	175
0.20°	+30°	220	165	77	22	33	10	8.8	7.0	180	130	66
0.50°	–4°	420	315	150	42	63	19	17	13	340	250	125
0.50°	+30°	150	110	53	15	23	7.0	6.0	5.0	120	90	45
1.00°	–4°	120	90	42	12	18	5.0	4.8	4.0	96	72	36
1.00°	+30°	45	34	16	5.0	7.0	2.0	1.8	1.0	36	27	14

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

samples may be weathered, and the results averaged, to decrease the effects of variability associated with the weathering process.

NOTE 5—Weathering tests are generally performed less frequently than other tests in this specification. Judgment must be used to satisfy the user that weathering results obtained on exposed samples are sufficiently applicable to the material being supplied.

7.7 *Colorfastness*—Use one of the outdoor-weathered specimens to test for colorfastness. Wash, dry, and condition panels in accordance with 7.6.2 and test as specified in 7.4.

7.8 *Shrinkage*—Condition a 9 by 9-in. (229 by 229-mm) retroreflective sheeting specimen with liner, a minimum of 1 h at standard test conditions (see 7.1). Remove the liner and place the specimen on a flat surface with the adhesive side up. Ten minutes after the liner is removed and again after 24 h, measure the specimen to determine the amount of dimensional change.

7.9 *Flexibility*—Bend the sheeting, in 1 s, around a ⅛-in. (3.2-mm) mandrel with adhesive contacting the mandrel. For ease of testing, spread talcum powder on the adhesive to prevent sticking to the mandrel. The test specimen shall be 2¾ by 11 in. (70 by 229 mm). The test temperature shall be 73 ± 3 °F (23 ± 2 °C).

7.10 *Liner Removal*—The protective liner, if any, shall be easily removed following accelerated storage for 4 h at 160 °F (71 °C) under a weight of 2.5 psi (17.2 kPa).

7.11 *Impact Resistance*—Apply the retroreflective sheeting to a 3 by 5 by 0.040-in. (76 by 127 by 1.016-mm) 6061-T6 aluminum test panel as specified in 7.2 and test condition as specified in 7.1. Utilizing the test instrument and procedures described in Test Method D2794, subject the sheeting to the impact of a 2-lb (0.91-kg) weight dropped from the height necessary to generate an impact of 10 in.-lb (1.13 N-m) when striking a ⅝-in. (15.8-mm) diameter rounded-tip indenter. The indention formed during this test shall be an intrusion (in which the panel is struck on the sheeting side and the panel is supported by a steel fixture having a cylindrical hole as described in Test Method D2794, Section 6.3).

TABLE 11 Color Specification Limits (Daytime)[A]

Color	1		2		3		4		5	
	x	y	x	y	x	y	x	y	x	y
White	0.303	0.300	0.368	0.366	0.340	0.393	0.274	0.329		
Yellow	0.498	0.412	0.557	0.442	0.479	0.520	0.438	0.472		
Orange	0.558	0.352	0.636	0.364	0.570	0.429	0.506	0.404		
Green[B]	0.026	0.399	0.166	0.364	0.286	0.446	0.207	0.771		
Red	0.565	0.346	0.629	0.281	0.735	0.265	0.648	0.351		
Blue[B]	0.140	0.035	0.244	0.210	0.190	0.255	0.065	0.216		
Purple	0.302	0.064	0.468	0.140	0.380	0.255	0.310	0.210		
Brown	0.430	0.340	0.610	0.390	0.550	0.450	0.430	0.390		
Fluorescent Yellow-Green	0.387	0.610	0.369	0.546	0.428	0.496	0.460	0.540		
Fluorescent Yellow	0.479	0.520	0.446	0.483	0.512	0.421	0.557	0.442		
Fluorescent Orange	0.583	0.416	0.535	0.400	0.595	0.351	0.645	0.355		
Fluorescent Pink	0.600	0.340	0.450	0.332	0.430	0.275	0.536	0.230	0.644	0.290

[A] The four pairs (five pairs for fluorescent pink) of chromaticity coordinates determine the acceptable color in terms of the CIE 1931 Standard Colorimetric System measured with CIE Standard Illuminant D65.
[B] The saturation limit of green and blue may extend to the border of the CIE chromaticity locus for spectral colors.

TABLE 12 Outdoor Weathering Photometric Requirements for All Climates

Type	Months[A]	Minimum Coefficient of Retroreflection, R_A
I	24[B]	50 % of Table 1
II	36[B]	65 % of Table 3
III	36[B]	80 % of Table 4
IV	36[B]	80 % of Table 5
V	36[B]	80 % of Table 6
VI	6	50 % of Table 7
VIII	36[B]	80 % of Table 8
IX	36[B]	80 % of Table 9
XI	36[B]	80 % of Table 10

[A] Testing at shorter intervals may be done to gather additional information.
[B] When sheeting is specified for construction work zone applications, the outdoor weathering shall be twelve months.

NOTE 6—Test Method D2794 requires the use of a separate weight that falls onto an indenter having a rounded tip. Caution: some impact test equipment contains a combined weight and indenter having a rounded tip. The use of this combined weight and indenter will result in more severe damage to the sample as compared to the separate weight and indenter condition. Users are advised that results from the two different test fixtures are not comparable.

7.12 *Nighttime Color*—Test for nighttime color. Determine the chromaticity in accordance with Test Method E3165 (and further described in Practice E811 and evaluated using the CIE system in Practice E308). (The saturation limit shall be considered to extend to the boundary of the chromaticity locus of spectral colors.)

8. General Requirements

8.1 *Sheets*—When the retroreflective material is in sheet form, the design, dimension, and tolerances shall be as specified by the purchaser.

8.2 *Rolls*—When ordered in rolls, the retroreflective material shall be evenly wound on a core of sufficient rigidity to prevent distortion of the roll. The maximum number of splices shall be 4/50-yd (46-m) roll. Each splice shall be visible at the edge of the roll. The length and width will be specified by the purchaser.

8.3 *Color Processing*—The sheeting shall permit color processing with compatible transparent and opaque process colors in accordance with the sheeting manufacturer's recommendation at temperatures between 60 to 100 °F (16 to 38 °C) and relative humidity at 20 to 80 %.

9. Sampling

9.1 To determine conformance to requirements for coefficients of retroreflection for rolls or sheets at least 1 yd (0.914 m) long of retroreflective sheeting in new (unexposed) condition:

9.1.1 A full width by 1 yd (0.914 m) long specimen is selected at random to represent the entire sheet, roll, or lot.

NOTE 7—Samples smaller than 1 yd (0.914 m) long should not be used to judge conformance for full rolls or lots.

9.1.2 Three samples are taken from the selected specimen.

9.1.2.1 The three samples shall be spaced evenly across (left, center, right) and spaced evenly down the specimen as shown in the examples in Fig. 3.

9.2 For determining conformance to all other requirements, single samples taken at random shall be tested.

10. Precision and Bias

10.1 The precision and bias for the test methods in Section 7 have not been determined.

11. Packaging and Package Marking

11.1 The sheets or rolls manufactured under this specification shall be packaged in accordance with commercially acceptable standards. Each package shall be marked with the following:

Name, Brand, or Trademark
Quantity
Size
Lot or Run Number
Part Number

12. Keywords

12.1 barricades; delineators; highway signing; reboundable sheeting; retroreflective sheeting; traffic control

TABLE 13 Color Specification Limits (Nighttime)[A]

Color	1		2		3		4	
	x	y	x	y	x	y	x	y
White	0.475	0.452	0.360	0.415	0.392	0.370	0.515	0.409
Yellow	0.513	0.487	0.500	0.470	0.545	0.425	0.572	0.425
Orange	0.595	0.405	0.565	0.405	0.613	0.355	0.643	0.355
Green	0.007	0.570	0.200	0.500	0.322	0.590	0.193	0.782
Red	0.650	0.348	0.620	0.348	0.712	0.255	0.735	0.265
Blue	0.091	0.133	0.230	0.240	0.180	0.370	0.033	0.370
Purple	0.355	0.088	0.635	0.221	0.500	0.350	0.385	0.288
Brown	0.595	0.405	0.540	0.405	0.570	0.365	0.643	0.355
Fluorescent Yellow-Green	0.480	0.520	0.473	0.490	0.523	0.440	0.550	0.449
Fluorescent Yellow	0.554	0.445	0.526	0.437	0.569	0.394	0.610	0.390
Fluorescent Orange	0.625	0.375	0.589	0.376	0.636	0.330	0.669	0.331

[A] The four pairs of chromaticity coordinates determine the acceptable color in terms of the CIE 1931 Standard Colorimetric System measured with CIE Standard Illuminant A.

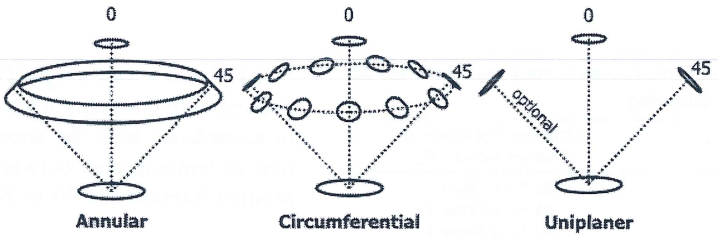

FIG. 1 Three Types of 0/45 (45/0) Instrument

TABLE 14 Climate Types for Use in Outdoor Exposures of Retroreflective Sheetings

Climate Type[A,B]	Mean Monthly Temperature, °F (°C)		Representative Example of a Typical Location
	Warmest Month	Coldest Month	
Tropical summer rain	82 to 93 (28 to 34)	64 to 72 (18 to 22)	Miami, FL
Desert	82 to 93 (28 to 34)	50 to 63 (10 to 17)	Phoenix, AZ
(optional, but recommended)	Climate mutually agreed upon between the purchaser and the seller[C]		

[A] Climate classification is in accordance with the Koppen reformed classification system.
[B] Outdoor exposure results from Miami, FL and Phoenix, AZ are recognized internationally as benchmarks for evaluating durability of many different types of material and products.
[C] Outdoor exposures of retroreflective sheeting materials are conducted in locations representative of several different climates by the National Transportation Product Evaluation Program (NTPEP) run by AASHTO.

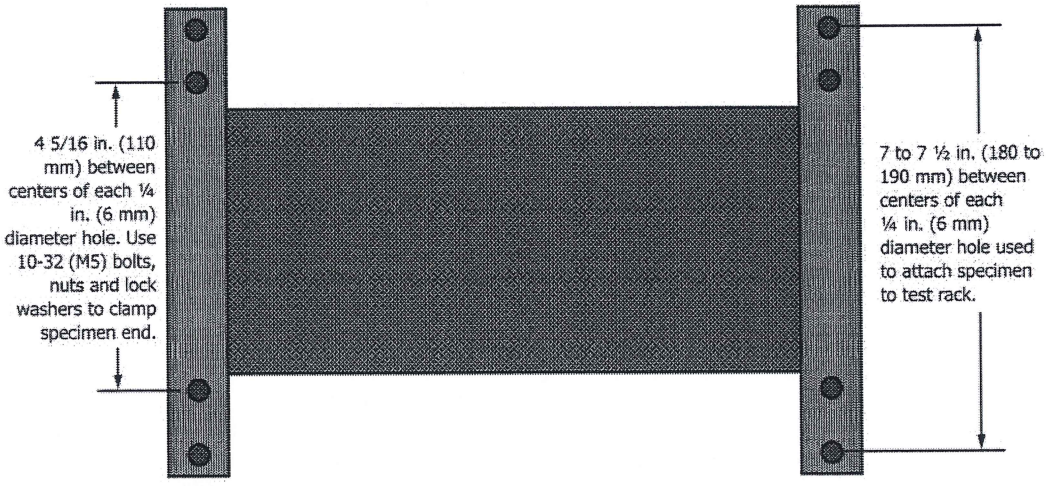

FIG. 2 Diagram Showing Clamping Bars Used for Attaching Type VI Sheeting Specimens to Test Rack for Outdoor Exposure

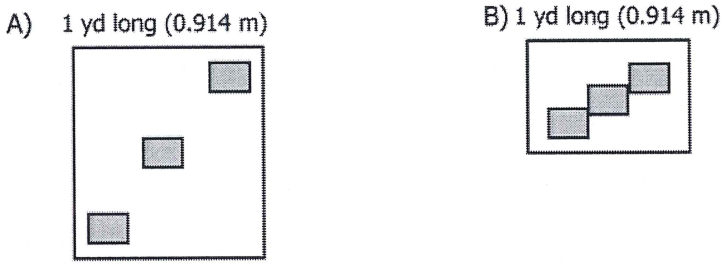

FIG. 3 Examples of Proper Spacing for Samples

SUPPLEMENTARY REQUIREMENTS

The following supplementary requirements shall apply only when specified by the purchaser in the contract or order.

S1. Fungus Resistance

S1.1 *Scope*—This supplementary specification covers fungus-resistance testing.

S1.2 *Test Requirements and Test Methods:*

S1.2.1 *Test Condition*—Unless otherwise specified in this specification, all adhesively bonded and unbonded test samples and specimens shall be conditioned at a temperature of 73 ± 3 °F (23 ± 2 °C) and 50 ± 5 % relative humidity for 24 h prior to testing.

S1.2.2 *Panel Preparations*—Unless otherwise specified in this specification, when tests are to be performed using test panels, the specimens of retroreflective material shall be applied to smooth aluminum cut from Alloy 6061-T6, in accordance with Specification B209 or B209M, sheets in 0.020-in. (0.508-mm) thickness. The aluminum shall be prepared in accordance with Specification B449, Class 2 or degreased and lightly acid etched before the specimens are applied. The specimens shall be applied to the panels in accordance with the recommendations of the retroreflective sheeting manufacturer.

S1.3 *Fungus Resistance:*

S1.3.1 For use in areas where fungus growth on retroreflective sheeting may be a problem, fungus resistance shall be determined as specified herein.

S1.3.2 After inoculation with the test organism, *Aspergillus niger*, and incubation for 14 days, the retroreflective material shall show no appreciable formation of fungus growth. Any formation of fungus growth shall be noninjurious to the retroreflective material and shall be removable by wiping with a soft cloth.

S1.3.3 *Test Organism*—The test organism used in this test shall be *Aspergillus niger*, ATCC Number 6275.[5] Cultures of this organism shall be carefully maintained on a potato-dextrose agar medium and promptly renewed if there is evidence of contamination. The stock cultures may be kept for not more than four months in a refrigerator at a temperature between 37 to 50 °F (3 to 10 °C). Subcultures incubated

[5] Available from the American Type Culture Collection (ATCC), 12301 Parklawn Dr., Rockville, MD 20852, or Mycology Laboratory, PRL, U.S. Army Natick Laboratories, Natick, MA 01760.

between 82.4 to 86 °F (28 to 30 °C) for 10 to 14 days shall be used in preparing the inoculum.

S1.3.4 *Culture Medium*—The culture medium shall have the following composition:

$NaNO_3$	3.0 g
K_2HPO_4	1.0 g
$MgSO_4 \cdot 7H_2O$	0.5 g
KCl	0.25 g
Agar	15.0 g
Distilled water to make 1000 mL.	

S1.3.5 The pH shall be 5.5 to 6.5; if otherwise, adjust to that range with HCl or NaOH. After mixing, the ingredients shall be sterilized by autoclaving for 15 min at 15 psi (103 kPa) at 248 °F (120 °C). Under sterile conditions, the medium shall be poured into six petri dishes (150 by 20 mm), about 2.2 oz (65 mL) per dish, and allowed to harden.

S1.3.6 *Inoculum*—Add about 0.34 oz (10 mL) of sterile, distilled water containing about 0.005 % of nontoxic wetting agent to a subculture (10 to 14 days old) of the test organism in a ripe, fruiting condition. The spores shall be forced into suspension with a sterile camel's hair brush (or other suitable means) and diluted to 3.4 oz (100 mL) with sterile, distilled water.

S1.3.7 *Preparation of Specimens*—Cut three 3 by 3-in. (76 by 76-mm) specimens from the sample and apply to test panels with the retroreflective surface up. Completely immerse the test specimens in a leaching tank of continuously flowing water for 24 h and then remove and dry. The leaching tank shall be large enough to hold an amount of water weighing not less than 50× the weight of the specimens. The water entering the tank shall not fall directly on the specimens and shall flow at a rate of 1.3 to 2.6 gal/h (5 to 10 L/h). The pH of the water shall be in the range of 6.0 to 8.0.

S1.3.8 *Inoculation*—Under aseptic conditions, dip each specimen in 70 % ethanol for a few seconds, rinse in distilled water, and place firmly on the surface of the solidified agar medium contained in the petri dishes. Place specimens with the retroreflective surface facing up, one specimen to each dish. With a sterile pipette, distribute 0.03 to 0.05 oz (1.0 to 1.5 mL) of inoculum over the surface of each specimen and the surrounding medium.

S1.3.9 *Incubation Period*—The period of incubation shall be 14 days at a temperature between 84.2 to 89.6 °F (28.9 to 32 °C) and 85 to 90 % relative humidity.

S1.3.10 *Control*—Test three control specimens of untreated, porous-grade filter paper with the specimens of the retroreflective material to check the viability of the inoculum. At the end of the incubation period, the controls should be covered with fungus growth.

S1.3.11 *Test Results*—Upon completion of the incubation period, examine the specimens visually for fungus growth. Wipe the specimens with a soft cloth wet with a 70 % ethanol solution. Visually examine the specimens for damage resulting from fungus growth. If no pitting or textured surface is found, the sample will be reported to have passed.

S2. Reboundable Sheeting Requirements

NOTE S2.1—Not all types of sheeting are available in reboundable form.

S2.1 *Performance Requirements:*

S2.1.1 *Impact Resistance*—Retroreflective sheeting shall show no cracking or delamination outside of the actual area of impact when subjected to the impact test in accordance with S2.2.1.

S2.1.2 *Flexibility Requirements*—The sheeting shall be sufficiently flexible to show no cracking when tested in accordance with S2.2.2.

S2.1.3 *Adhesion*—When tested in accordance with S2.2.3, the adhesive backing of the retroreflective sheeting shall produce a bond to support a 1¾-lb (0.79-kg) weight for adhesive classes 1, 2, and 3 or a 1-lb (0.45-kg) weight for adhesive class 4 for 5 min, without the bond peeling for a distance of more than 1 in. (25.4 mm).

S2.1.4 *Outdoor Weathering*—The retroreflective sheeting shall be weather resistant and show no appreciable cracking, scaling, pitting, blistering, edge lifting, or curling, or more than 1/32-in. (0.8-mm) shrinkage or expansion after outdoor exposures specified in 7.6. The outdoor exposure time and minimum coefficient of retroreflection (R_A) after exposure are specified in Table S2.1. Retroreflectivity measurements after outdoor weathering will be made only at 0.2° observation and −4 and +30° entrance angles.

S2.2 *Test Method:*

S2.2.1 *Impact Resistance*—Apply the retroreflective sheeting to a 3 by 5 by 0.040-in. (76 by 127 by 1.016-mm) 6061-T6 aluminum test panel as specified in 7.2 and test condition as specified in 7.1. Utilizing the test instrument and procedures described in Test Method D2794, subject the sheeting to the impact of a 4-lb (1.82-kg) weight, dropped from the height necessary to generate an impact of 100 in.-lb (11.3 N-m) when striking a 5/8-in. (15.8-mm) diameter rounded-tip indenter. The indention formed during this test shall be an intrusion (in which the panel is struck on the sheeting side and the panel is supported by a steel fixture having a cylindrical hole as described in Test Method D2794, Section 6.3).

NOTE S2.2—Test Method D2794 requires the use of a separate weight that falls onto on indenter having a rounded tip. Caution: some impact test equipment contains a combined weight and indenter having a rounded tip. The use of this combined weight and indenter will result in more severe damage to the sample as compared to the separate weight and indenter condition. Users are advised that results from the two different test fixtures are not comparable.

S2.2.2 *Flexibility*—The sheeting shall be bent, in 1 s, around a 1/8-in. (3.2-mm) mandrel with adhesive contacting the mandrel. For ease of testing, spread talcum powder on the

TABLE S2.1 Minimum Coefficient of Retroreflection (R_A) and Required Outdoor Exposure Times

Type	Months	Minimum Coefficient of Retroreflection (R_A)
I	12	65 % of Table 1
II	12	65 % of Table 3
III	12	80 % of Table 4
IV	12	80 % of Table 5
V	12	80 % of Table 6
VI	6	50 % of Table 7
VIII	12	80 % of Table 8
IX	12	80 % of Table 9
XI	12	80 % of Table 10

adhesive to prevent sticking to the mandrel. The test specimen shall be 2¾ by 11 in. (70 by 279 mm). The test temperature shall be 32 °F (0 °C).

S2.2.3 *Adhesion*—Apply the sheeting to a test panel, 0.040-in. (1.016-mm) minimum thickness, prepared as specified in 7.2. Bond 4 in. of a 1 by 6-in. (25.4 by 152-mm) specimen to a test panel. Condition (see 7.1) and then attach the weight to the free end and allow it to hang free at an angle of 90° to the panel surface for 5 min, without the bond peeling for more than 1 in. (25.4 mm).

S2.2.4 *Outdoor Weathering*—Test two panels in each location in accordance with Table 14. After panels have been exposed for the number of months listed in S2.1.4, wash and condition them in accordance with 7.6.2, then test for coefficient of retroreflection. Report the average of the coefficient of retroreflection measured at each geometry on the two panels from each exposure location.

S3. Artificial Accelerated Weathering

S3.1 *Scope*—This supplementary test may be used for provisional qualification of retroreflective sheeting in the interim period until the results from accelerated outdoor weathering are available (see 7.6). The results from accelerated outdoor weathering shall supersede and take precedence over the results from artificial accelerated weathering tests.

S3.2 *Test Specimens*—Expose three replicate specimens. Each test specimen shall be a minimum of 2.5 in. by 2.5 in. (64 mm by 64 mm)

S3.3 *Test Conditions*—Conduct exposures in a xenon arc exposure apparatus to simulate direct exposure to solar radiation. Operate the exposure apparatus in accordance with the basic principles and operating procedures of Practice G155 for using xenon arc and water apparatus intended to reproduce the weathering effects that occur when materials are exposed to sunlight, heat, and moisture as rain or dew in actual use.

NOTE S3.1—Results from artificial accelerated weathering tests are best used to compare the relative stability of materials. Reproducibility between laboratories has been shown to be good when the stability of materials is evaluated in terms of performance ranking compared to a control material of similar composition and construction and known outdoor stability; therefore, exposure of a control material at the same time as the test material is strongly recommended (see Practice G151).

S3.3.1 *Simulation of Terrestrial Daylight*—The xenon arc shall be filtered to provide a simulation of terrestrial daylight. The spectral power distribution of the filtered xenon arc shall conform to the Relative Ultraviolet Spectral Power Distribution Specification for Xenon Arc with Daylight Filters in Practice G155, Table 1.

S3.3.2 *Exposure Test Methods*—Three methods are provided for testing to determine conformance to provisional weathering requirements. These methods correspond to international practices for artificial accelerated weathering. Method I is equivalent to ISO 4892-2:2006/Amd.1:2009 Cycle 10, Method II is equivalent to Practice G155 Cycle 1, and Method III is equivalent to ISO 4892-2:2006 Cycle 1. Control the exposure conditions according to the exposure set point parameters in Table S3.1.

NOTE S3.2—The operational fluctuations given in Table S3.1 do not imply that the user is allowed to program a set point higher or lower than the exact set point specified. They refer to allowable deviations from the set point in the reading observed at the control sensor during equilibrium operating conditions. These deviations are the result of normal operational variations in apparatus. If the operational fluctuation is greater than the maximum allowable specified in Table S3.1, discontinue the test until the problem is resolved

S3.3.2.1 Results obtained using any of the methods shall be accepted for showing conformance to this supplementary requirement.

NOTE S3.3—Method III meets the requirements of EN 12899-1:2007. The historical practice within CEN and ISO has been to specify the Black Standard Thermometer for controlling temperature in xenon arc apparatus.

TABLE S3.1 Xenon Arc Apparatus Operating Conditions and Set Points

Exposure Parameters	Method I	Method II	Method III
Irradiance set point at 340 nm[A]	0.51 W/ (m²·nm)	0.35 W/ (m²·nm)	0.51 W/ (m²·nm)
Light/Dark Cycle	Continuous light	Continuous light	Continuous light
Uninsulated Black Panel Temperature set point[B]	63 °C	63 °C	na
Black Standard Thermometer Temperature set point[B]	na	na	65 °C
Water Spray Cycle[C]	Alternating periods of 102 minutes light only and 18 minutes light + water spray	Alternating periods of 102 minutes light only and 18 minutes light + water spray	Alternating periods of 102 minutes light only and 18 minutes light + water spray
Relative Humidity set point[D]	50 % during the light only period (optional)	50 % during the light only period (optional)	50 % during the light only period
Chamber Air Temperature[E]	38 °C (optional)	38 °C (optional)	38 °C

[A] The allowed deviation from the stated irradiance indicated by the device used to monitor irradiance at 340 nm is ±0.02 W/ (m²·nm) during equilibrium conditions.
[B] The allowed deviation from the stated temperature indicated by the device used to monitor temperature is ±2.5 °C during equilibrium conditions.
[C] Water spray refers to water sprayed on the exposed surface of the test specimens.
[D] When chamber humidity control is used, the control set point shall apply only to the light only period with an allowed deviation from the stated relative humidity indicated by the device used to monitor humidity of ±10 % during equilibrium conditions.
[E] When chamber air temperature control is used, the allowed deviation from the stated temperature indicated by the device used to monitor chamber temperature is ±2 °C during equilibrium conditions. Xenon arc exposures are typically run with either chamber air temperature controlled (automatically maintained by the apparatus at a specified set point value) or uncontrolled, which allows the air temperature in the chamber to find its own level during the test cycle. While most models of xenon arc apparatus now allow for chamber air temperature control, some older models do not have this capability.

TABLE S3.2 Radiant Exposure Requirements for Artificial Accelerated Weathering with Corresponding Exposure Times and Retained Photometric Requirements

Retroreflective Sheeting Type	Radiant exposure @ 340 nm (kJ/(m²·nm))	Methods I & III Exposure Time (hours)	Method II Exposure Time (hours)	Minimum Coefficient of Retroreflection, R_A
I	1840	1000	1460	50% of Table 1
II	3670[A]	2000	2915	65% of Table 3
III	3670[A]	2000	2915	80% of Table 4
IV	3670[A]	2000	2915	80% of Table 5
V	3670	2000	2915	80% of Table 6
VI	460	250	365	50% of Table 7
VIII	3670[A]	2000	2915	80% of Table 8
IX	3670[A]	2000	2915	80% of Table 9
XI	3670[A]	2000	2915	80% of Table 10

[A] When sheeting is specified for construction work zone applications, the minimum radiant exposure shall be 920 kJ/(m²·nm) at 340 nm (equivalent to 500 hours using Methods I or III and 730 hours exposure using Method II).

S3.3.3 *Xenon Arc Irradiance Setting*—The recommended irradiance set point is 0.51 W/(m²·nm) at 340 nm. However, to accommodate testing in xenon arc machines set at 0.35 W/(m²·nm) at 340 nm specified for other types of specimens being tested at the same time, the option is given to test retroreflective sheeting at the lower irradiance level. Therefore, the test duration is specified in terms of radiant exposure rather than time in order to provide equivalent radiant exposures at the different irradiance levels.

NOTE S3.4—Rationale for the xenon arc recommended irradiance setting of 0.51 W/(m²·nm) at 340 nm: (*1*) Data on spectral solar irradiance as a function of time of day in Miami, Florida and Phoenix, Arizona show that for approximately two to three hours before and after local noon, the irradiance on a surface angled 45° from the horizontal and facing the equator is at least 0.50 W/(m²·nm) at 340 nm for a significant portion of the year. Thus, the xenon arc irradiance of 0.51 W/(m²·nm) at 340 nm is representative of solar irradiance levels to which retroreflective sheeting is exposed in the accelerated outdoor benchmark exposure sites; (2) The recommendation is also made to encourage harmonization among international standards for artificial accelerated weathering of retroreflective sheeting. In ISO standards for xenon arc exposures using daylight filters, the irradiance set point is generally specified as 60 W/m² in the spectral region 300 nm to 400 nm, which corresponds to 0.51 W/(m²·nm) at 340 nm.

NOTE S3.5—Radiant energy is not the sole weathering factor responsible for degradation of polymeric materials. Method II runs at a lower irradiance set point requiring longer test duration to accumulate the specified radiant exposure. This longer exposure time may, for some retroreflective sheeting, produce greater changes in properties than the higher irradiance methods due to the consequent longer residence time at high temperature.

S3.4 *Test Requirements*—Expose specimens to the radiant exposure required in Table S3.2. After exposure, wash and condition the specimens in accordance with 7.6.2.

NOTE S3.6—When specimens are removed from the weathering device, it should be during the light-only period of the test cycle.

NOTE S3.7—General relationship between artificial accelerated weathering and accelerated outdoor weathering requirements: The 20-year annual average total UV (295-385 nm) radiant dosage on a surface angled 45° from the horizontal and facing the equator for Miami, Florida and Phoenix, Arizona are 283 MJ/m² and 331 MJ/m², respectively. A test specimen exposed to 3670 kJ/(m²·nm) at 340 nm in a typical xenon arc apparatus with daylight filters will have received a total UV (295-385 nm) radiant dosage on the order of 330 MJ/m². The artificial accelerated weathering simulates the radiant dosage received during approximately one year of accelerated outdoor weathering at the benchmark exposure sites.

S3.4.1 Conduct coefficient of retroreflection measurements of each replicate specimen after exposure at 0.2° observation angle and at –4° and +30° entrance angles in accordance with Test Method E810. For each combination of entrance and observation angle, the average of the replicate specimens shall meet or exceed the minimum requirements for the applicable type in Table S3.2.

S3.4.2 After exposure, the test specimens shall show no appreciable cracking, scaling, pitting, blistering, edge lifting, or curling of more than 1/32 in. (0.8 mm) shrinkage or expansion.

S3.4.3 After exposure, measure the daytime color of each replicate specimen in accordance with 7.4. The daytime color of the retroreflective sheeting shall conform to requirements of Table 2 and Table 11 for the appropriate type of sheeting.

APPENDIXES

(Nonmandatory Information)

X1. RELATED INFORMATION

X1.1 Other Specifications

X1.1.1 American Association of State Highway and Transportation Officials. AASHTO designation M 268.[6]

[6] Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, http://www.transportation.org.

X2. CORRECTION FACTORS FOR CONVERSION FROM ILLUMINANT C TO ILLUMINANT D65

X2.1 Table X2.1 lists the correction factors to change measurements made using Illuminant C to approximate measurements made using Illuminant D65.

TABLE X2.1 Correction Factors for Conversion from Illuminant C to Illuminant D65

NOTE 1—As an example, a blue sample which measured (x, y, Y) = (0.150, 0.150, 5.0) using Illuminant C would be converted to (0.149, 0.158, 5.0) to provide the result using Illuminant D65.

Color	x	y	Y
White	+0.003	+0.014	0.00
Yellow	+0.001	+0.002	0.00
Orange	+0.001	+0.001	0.00
Green	+0.000	+0.019	0.00
Red	+0.000	+0.001	0.00
Blue	−0.001	+0.008	0.00
Brown	+0.000	0.000	0.00

X3. SUPPLEMENTARY R_A VALUES FOR 0.1° OBSERVATION ANGLE

X3.1 Tables X3.1-X3.7 list the suggested minimum R_A values at 0.1° observation angle for each sheeting type contained within the main section of the standard. There are no suggested minimum R_A values at 0.1° observation angle for Types I and II. The values for 0.1° observation angle are supplementary requirements that shall only apply when specified by the purchaser in the contract or order.

TABLE X3.1 Type III Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Brown
0.1°	–4°	300	200	120	54	54	24	14
0.1°	+30°	180	120	72	32	32	14	10

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE X3.2 Type IV Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Brown	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange
0.10°	–4°	500	380	200	70	90	42	20	25	400	300	150
0.10°	+30°	240	175	94	32	42	20	10	12	185	140	70

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE X3.3 Type V Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple
0.10°	–4°	2000	1300	800	360	360	160	80
0.10°	+30°	1100	740	440	200	200	88	45

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE X3.4 Type VI Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange	Fluorescent Pink
0.10°	–4°	750	525	190	90	105	68	30	600	450	300	225
0.10°	+30°	300	210	75	36	42	27	12	240	180	120	90

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE X3.5 Type VIII Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Brown	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange
0.10°	–4°	1000	750	375	100	150	45	40	30	800	600	300
0.10°	+30°	460	345	175	46	69	21	18	14	370	280	135

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE X3.6 Type IX Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange
0.10°	–4°	660	500	250	66	130	30	26	530	400	200
0.10°	+30°	370	280	140	37	74	17	15	300	220	110

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).

TABLE X3.7 Type XI Sheeting[A]

Observation Angle	Entrance Angle	White	Yellow	Orange	Green	Red	Blue	Purple	Brown	Fluorescent Yellow-Green	Fluorescent Yellow	Fluorescent Orange
0.10°	–4°	830	620	290	83	125	37	33	25	660	500	250
0.10°	+30°	325	245	115	33	50	15	13	10	260	200	100

[A] Minimum Coefficient of Retroreflection (R_A) cd/fc/ft^2 (cd·lx^{-1}·m^{-2}).