Designation: E2355 – 10

Standard Test Method for Measuring the Visible Light Transmission Uniformity of an Absorptive Electrochromic Coating on a Glazing Surface[1]

This standard is issued under the fixed designation E2355; 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 The test described is a method for measuring the uniformity of an absorptive electrochromic coating (ECC) in a static colored or bleached state on a glazing surface, which is or will be one of two or more glazings in a preassembled permanently sealed insulating glass unit (IGU).

1.2 The test method is applicable only for layered (one or more active coatings between the TCOs) absorptive ECCs on vision glass (superstrate and substrate) areas planned for use in buildings, such as glass doors, windows, skylights, and exterior wall systems. The layers used for electrochromically changing the optical properties may be inorganic or organic materials between the superstrate and substrate and may include laminates.

1.3 The test method is not applicable to other types of coatings on vision glass with other chromogenic coatings that cannot be held in a static colored or bleached state.

1.4 The test method is not applicable to IGUs that will be constructed from superstrate or substrate materials other than glass.

1.5 The test method is not applicable for measuring the uniformity of ECC coatings during the coloring or bleaching processes.

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

1.7 There is no comparable International Standards Organization Standard.

1.8 *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 requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation

C1048 Specification for Heat-Strengthened and Fully Tempered Flat Glass

E2141 Test Method for Accelerated Aging of Electrochromic Devices in Sealed Insulating Glass Units

E2188 Test Method for Insulating Glass Unit Performance

E2189 Test Method for Testing Resistance to Fogging in Insulating Glass Units

E2190 Specification for Insulating Glass Unit Performance and Evaluation

E2240 Test Method for Assessing the Current-Voltage Cycling Stability at 90°C (194°F) of Absorptive Electrochromic Coatings on Sealed Insulating Glass Units (Withdrawn 2015)[3]

E2241 Test Method for Assessing the Current-Voltage Cycling Stability at Room Temperature of Absorptive Electrochromic Coatings on Sealed Insulating Glass Units (Withdrawn 2015)[3]

3. Terminology

3.1 *Definitions*—Refer to Terminology C168 for definitions of general terms.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bleached state*—a descriptor for an EC coating when no ions reside in the electrochromic layer or after ions have been removed (or inserted, depending on the type of material) from the electrochromic layer(s) and if applicable, the maximum number of ions have been returned to the counterelectrode layer to restore the photopic optical specular transmittance in the bleached state (τ_b) from that of the photopic optical specular transmittance in the colored state (τ_c).

3.2.2 *colored state*—a descriptor for an EC coating after ions have been inserted (or removed, depending on the type of

[1] This test method is under the jurisdiction of ASTM Committee E06 on Performance of Buildings and is the direct responsibility of Subcommittee E06.22 on Durability Performance of Building Constructions.

Current edition approved Oct. 1, 2010. Published November 2010. Originally approved in 2004. Last previous edition approved in 2004 as E2355– 04. DOI: 10.1520/E2355-10.

[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] The last approved version of this historical standard is referenced on www.astm.org.

material) into the electrochromic layer and, if applicable, removed from the counterelectrode layer to reduce the photopic optical specular transmittance (of wavelengths from 400 nm to 730 nm) from that in the bleached state (τ_b).

3.2.3 *durability*—the capability of maintaining the serviceability of a product, component, assembly, or construction over a specified time.

3.2.4 *electrochromic coating (ECC)*—the multilayered materials that include the electrochromic layers, other layers, and transparent conducting oxide layers required for altering the optical properties of the coating.

3.2.5 *electrochromic layer(s)*—the material(s) in an EC glazing that alter its optical properties in response to the insertion or removal of ions, for example, Li^+ or H^+.

3.2.6 *electrochromic (EC) glazing*—a device with an ECC consisting of several layers of electrochromic and attendant materials and one or more lites of glass, which are able to alter their optical properties in response to a change in an applied electric field. The changeable optical properties include transmittance, reflectance, and absorptance result in changes in the solar heat gain, visible transmittance, and U-factor of the glass.

3.2.7 *fenestration*—any opening in a building's envelope including windows, doors, and skylights.

3.2.8 *performance parameters*—the photopic transmittance ratio (PTR) between the bleached and colored states; coloring and bleaching times; and open-circuit memory.

3.2.9 *photopic transmission ratio (PRT)*—the ratio of the photopic transmission in the highest transmission, bleached state (τ_b) to the photopic transmission in the lowest transmission (colored) state, (τ_c). PTR= τ_b / τ_c.

3.2.10 *sealed insulating glass unit*—is defined in Specification E2190 but see also Appendix X1, Section X1.3.

3.2.11 *serviceability*—the capability of a building product, component, assembly, or construction to perform the function(s) for which it was designed and constructed.

3.2.12 *uniformity*—the variation in visible light transmission within an EC glazing.

3.3 For additional useful definitions for terminology used in this standard, see Appendix X1, Section X1.3.

4. Significance and Use

4.1 The ECCs used in the test method will ultimately be exposed (Test Method E2141) to solar radiation and deployed to control the amount of radiation by absorption and reflection and thus, limit the solar heat gain and amount of solar radiation that is transmitted into the building.

4.2 The test method referenced herein is a laboratory test conducted under specified conditions. This test method is intended for use in assessing the changes in uniformity of an ECC on vision glass and subjected to a series of tests for assessing the durability of the coating or the IGU unit, or both.

4.3 The useful life of IGUs with an absorptive ECC may depend on their ability to maintain an acceptable uniformity when used in an IGU for buildings applications. As described in Section 1.[4] (See Appendix X1, X1.4 and X1.5), this test method is intended to provide a means for measuring the uniformity of an absorptive electrochromic coating (ECC) on a glazing surface (including when sealed in an insulating glass unit).

4.4 *Effects of Test Procedures*—Data generated using this test method may be used to evaluate and compare the effects of subjecting ECCs in IGUs to the accelerated weathering procedures described in Test Methods E2141, E2240, or E2241. This test method requires the measurement of uniformity as a basis for evaluating changes in one of several performance parameters.

4.4.1 Changes in the uniformity of the test specimens may vary from none to significant. Some physical changes in the specimens may be visible when there are no apparent changes in the performance. Similarly, performance changes may occur with no visible changes in the specimens.

4.4.2 All conditions of measurement in this test method must be described in the report so that an assessment of their significance can be made.

4.5 *Sequencing*—If this test method is performed as part of a combined sequence with other measurements of the ECC perfomance (see 8.2) and visual inspection (see 8.3 in Test Methods E2141, E2240, or E2241) determined at the end of one of the test methods, the result may be used as the initial uniformity measurement for the next test; duplication of these uniformity measurements is not necessary unless so specified.

5. Background

5.1 Durability is a critical requirement for and EC glazing product for use on the building envelope. In selecting the materials, device design, and glazing for any application, the ability of the glazing to perform over time is an indication of that glazing's durability. The purpose of this standard test method is to measure the uniformity of an absorptive electrochromic coating (ECC) on a glazing surface.

5.2 EC IGUs perform a number of important functions in a building envelope including: minimizing the solar energy heat gain; providing for passive solar energy gain; controlling a variable visual connection with the outside world; enhancing human comfort (heat gain), security, ventilation, illumination, and glare control; providing for architectural expression; and (possibly) improving acoustical performance. Some of these functions may deteriorate in performance over time. Large changes in the uniformity of an ECC on a glazing surface may result in an unacceptable visual connection with the outside world, illumination, glare control, or in the architectural expression by the fenestration product.

6. Apparatus

6.1 *Laboratory Space,* that is large enough for the largest ECC-glass specimen to be measured and that will maintain the

[4] Czanderna, A. W., Benson, D. K., Jorgensen, G. J., Zhang, J-G., Tracy, C. E., and Deb, S. K., "Durability Issues and Service Lifetime Prediction of Electrochromic Windows for Buildings Applications," NREL/TP-510-22702, *National Renewable Energy Laboratory*, Golden, CO, May 1997; Solar Energy Materials and Solar Cells, 56, 1999, pp. 419-436.

ECC testing temperature at 22 ± 3°C (72 ± 5°F). The space must permit using the equipment needed for making the uniformity measurements.

6.2 *Positioning Mechanism,* that will hold and position the light source-detector pair(s) above and under the ECC sample. Because the sample sizes can vary, the light source-detector pair(s) shall be moveable and adjustable.

6.3 *Holding Mechanism,* that will hold a coated glass specimen in the central position between the light source and detector and that maintains the correct beam size diameter (within the allowed tolerance). The repeatability of positioning is to be ±3 mm. Clamp the source and detector pair to the glass during measurement to avoid stray light.

6.4 *Computer Controlled Photodiode Array Spectrophotometer,* for obtaining and storing data from the electro-optical characterization of the optical transmittance in the colored and bleached state. The resolution of the transmittance (T) measurement shall be 0.1 %T.

6.4.1 *Broadband Lamp,* that will provide a broadband spectrum from the light source and that must be compatible with illuminating the photodiode array spectrophotometer described in 6.4 and that will provide sufficient intensity from 400 to 720 nm. The illumination spot size of the source on the sample shall be 50 ± 3 mm in diameter. Choose a source of "cool" light to minimize localized heating that could adversely impact the uniformity of the ECC. The stability of the lamp for making the transmittance measurements shall be sufficient to provide the needed accuracy and precision.

NOTE 1—A 5-cm diameter spot size provides good reproducibility of the measurement of any broad non-uniformities in the ECC and allows precision measurements to be made without placing tight tolerances on the position of the spot. The measurement may also be made with a smaller spot size, for example, 2-cm that is sequentially positioned until the area of a 5-cm diameter circle has been sampled.

6.4.2 *Transmittance Measurements,* to a precision of ±0.5 % T and with an accuracy of ±2 % of the measured transmittance or ±0.5 % in transmittance, whichever is the greater.

NOTE 2—The accuracy is ±0.5 % in the measured transmittance up to T = 25 % and then 2 % of the transmittance value for all T > 25 %. Thus, the two criteria prevent specifying an unrealistic measurement accuracy at small values of T, such as in the colored state.

6.5 *Transmission Standards,* to calibrate the equipment appropriately. To calibrate the transmittance (T) measurements, select transmission standards that span the entire dynamic range to be measured. For example, if an ECC sample with a dynamic transmittance range of 55 to 4 % is to be measured, calibration standards in the range of T = 3 to 5 % and in the range of T = 50 to 60 % are required.

6.6 *Temperature Measurement Equipment*—Use an instrument or instruments to measure the temperature of the specimen during the uniformity measurements. The results shall be accurate to ±0.1°C (±0.2°F) with a total error of less than ±0.3°C (±0.5°F) of the reading.

6.7 *Temperature Sensors,* suitable for the room temperature range, such as thermocouples, are attached to the portions of the test specimens that will provide the best measurement of the ECC temperature. If more than one specimen of identical size, design, and construction is tested simultaneously, it is not necessary to monitor the temperature of all identical specimens.

6.8 *Voltage Cycling Unit,* for imposing voltage cycles to alternately color and bleach the ECCs from a fully bleached state to the fully colored state and back to the fully bleached state.

6.9 *Digital Camera,* for taking photographs of the specimens.

7. Test Specimen

7.1 Test specimen size, design, and construction shall be established and specified by the user of this standard, except the specimens shall be at least 250 by 250-mm.

NOTE 3—Consideration should be given to the ultimate requirement for testing specimens that are 355 ± 6 mm by 505 ± 6 mm such as those used in Test Methods E2188 and E2189, and for using heat-strengthened or tempered glass (see Specification C1048). Consult Section 5 in Test Method E2188 for a description of test specimens and their preparation.

NOTE 4—The test method may also be used for smaller, prototype EC IGUs or EC laminated structures for measuring the uniformity of an absorptive electrochromic coating (ECC) on a glazing surface.

7.2 Six test specimens that are represented to be "identical" shall be supplied for measuring the uniformity of an absorptive electrochromic coating (ECC) on a glazing surface, which will ultimately be one of two or more of the lites in a preassembled permanently sealed insulating glass unit (IGU).[4] (See Appendix X1, Section X1.5.)

7.3 The manufacturer shall provide control parameters and other information that are needed by the testing laboratory for carrying out this test.

7.4 The testing laboratory shall retain two of the supplied units as control specimens.

8. Procedure

8.1 *Overview*—Prior to making the uniformity measurements, the ECC sample shall be at a steady state, that is, the rate of change of transmittance at any given point on the area of the coating must be a minimum. The manufacturers shall provide the control hardware (ECC control system) and instructions for how to achieve this constant transmission state. To assure that steady state has been reached, the uniformity measurements should begin, as a guide, 30 min after a change to the colored or bleached state has been initiated. However, the time chosen for the onset of making uniformity measurements shall take into account variations in the dynamic response between samples from different manufacturers, of different technologies, and of different size. The temperature range for the testing environment and the sample being measured shall be 22 ± 3°C. Visible light transmittance shall be measured at a number of specified and fixed points on a sample as given in 8.6.

8.2 *Electro-optic Characterization*—Perform electro-optic characterization as described in Test Method E2141, sections 8.2 and 8.2.1 before and after making the uniformity measurements. Calculate the photopic transmittance ratio from the optical transmittance data in the bleached and colored states as