Designation: E2355 – 04

Standard Test Method for Measuring the 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 will ultimately be one of two or more glazings in a preassembled permanently sealed insulating glass unit (IGU). Cross sections of typical electrochromic windows (ECWs) have three to five-layers of coatings that include one to three active layers sandwiched between two transparent conducting electrodes (TCEs, see Section 3). Examples of the cross-sectional arrangements can be found[2] in "Evaluation Criteria and Test Methods for Electrochromic Windows." (For a list of acronyms used in this Standard, see Appendix X1, Section X1.1).

1.2 The test method is applicable only for layered (one or more active coatings between the TCEs) absorptive ECCs on vision glass (superstrate and substrate) areas planned for use in IGUs for 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 ECCs used in this 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.

1.4 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.

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

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

1.7 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, which will be incorporated into an IGU and subjected to a series of tests for assessing the durability of the coating or the IGU unit, or both.

1.8 The values stated in metric (SI) units are to be regarded as the standard.

1.9 There is no comparable International Standards Organization Standard.

1.10 *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:*[3]

C168 Terminology Relating to Thermal Insulation

C1048 Specification for Heat-Treated Flat Glass—Kind HS, Kind FT Coated and Uncoated Glass

E2094 Practice for Evaluating the Service Life of Chromogenic Glazings

E2141 Test Methods for Assessing the Durability of Absorptive Electrochromic Coatings on Sealed Insulating Glass Units

E2188 Test Method for Insulating Glass Unit Performance

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

E2241 Test Method for Assessing the Current-Voltage Cycling Stability at Room Temperature of Absorptive Electrochromic Coatings on Sealed Insulating Glass Units

2.2 *Canadian Standard:*

CAN/CGSB12.8 Insulating Glass Units

[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.

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[2] Czanderna, A. W., and Lampert, C. M., "Evaluation Criteria and Test Methods for Electrochromic Windows," *SERI/PR-255-3537*, Solar Energy Research Institute, Golden, CO, July 1990.

[3] 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. 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 *accelerated aging test*—an aging test in which the rate of degradation of building components or materials is intentionally accelerated from that expected in actual service.

3.2.2 *bleached state*—a descriptor for an ECW 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).

3.2.3 *chromogenic glazing*—is defined in Practice E2094, but also see Appendix X1, Section X1.3.

3.2.4 *colored state*—a descriptor for an ECW after ions have been inserted (or removed, depending on the type of 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).

3.2.5 *control parameters for an electrochromic coating (ECC)*—the time dependent voltage or current profile that is supplied by the manufacturer of the ECW in which the voltage or current is applied to the ECC for achieving and maintaining the desired colored state and subsequently bleaching of the device.

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

3.2.7 *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.

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

3.2.9 *electrochromic window (ECW)*—a device with an ECC consisting of several layers of electrochromic and attendant materials, 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 window.

3.2.10 *fenestration*—the placement of openings in a building, that is, a window, door, or skylight and its associated interior or exterior elements such as shades or blinds.

3.2.11 *ion conducting layer*—the material in an ECC through which ions are transported between the electrochromic layer and the ion storage layer and electron transport is minimized.

3.2.12 *ion storage layer or counter electrode layer*—the material in an ECC that serves as a reservoir for ions that can be inserted into the electrochromic layer.

3.2.13 *performance parameters*—the photopic transmittance ratio (PTR), of at least 5:1 (PTR = τ_b/τ_c) between the bleached (for example, τ_b of 60 to 70 %) and colored (for example, τ_c of 12 to 14 %) states; coloring and bleaching times of a few minutes; switching with applied voltages from ~1 to 3 V; and open-circuit memory of a few hours, for example, contemporary ECWs typically have open circuit memories of 6 to 24 h.

3.2.14 *sealed insulating glass unit*—is defined in Test Method E2190 but see also Appendix X1, Section X1.3.

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

3.2.16 *service life (of a building component or material)*—the period of time after installation during which all properties exceed minimum acceptable values when routinely maintained.

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 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 1.2[2,4] (See Appendix X1, Sections 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, which will ultimately be one of two or more of the glazings in a preassembled permanently sealed insulating glass unit (IGU).

4.2 *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 and Practice E2094. This test method requires the measurement of uniformity as a basis for evaluating changes in one of several performance parameters.

4.2.1 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.

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

4.3 *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 Observations and measurements have shown that some of the performance parameters of ECCs in ECWs have a

[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.

tendency to deteriorate over time. 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 ability of the product to perform over time, at or better than specified requirements, is an indication of the service life of the glazings. While these two indicators are related, the purpose of this standard test method is to measure the uniformity of an absorptive electrochromic coating (ECC) on a glazing surface, which will ultimately be one of two or more glazings in a preassembled permanently sealed insulating glass unit (IGU).

5.2 ECWs 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 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.

6.5 *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 5 ± 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.

6.6 *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 prevents specifying an unrealistic measurement accuracy at small values of T, such as in the colored state.

6.7 *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.

6.8 *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.

6.9 *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.

6.10 *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.

6.11 *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 (10 by 10-in.).

NOTE 3—Consideration should be given to the ultimate requirement for testing specimens that are 355 ± 6 mm by 505 ± 6 mm (14 ± ¼ in. by 20 ± ¼ in.) such as those used in Test Method E2188, and for using heat-strengthened or tempered glass (see Specification C1048). Consult Section 5 in Test Method E2188 and Section 12.1 in CAN/CGSB 12.8 for a description of test specimens and their preparation.

NOTE 4—The test method may also be used for smaller, prototype ECWs 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 glazings in a preassembled permanently sealed insulating glass unit (IGU).

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 glazings 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.