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Standard Guide for Assessing the Durability of Absorptive Electrochromic Coatings within Sealed Insulating Glass Units[1]

This standard is issued under the fixed designation E2354; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides the recommended sequence for using the referenced ASTM test methods for assessing the durability of absorptive electrochromic coatings (ECCs) within sealed insulating glass units. Cross sections of typical electrochromic glazings have three to five-layers of coatings that include one to three active layers sandwiched between two transparent conducting electrodes (TCOs, 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 This guide 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 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.

1.3 The ECCs used in this guide 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 This guide is not applicable to other types of coatings on vision glass with other chromogenic coatings, for example, photochromic and thermochromic coatings.

1.5 This guide is not applicable to IGUs that will be constructed from superstrate or substrate materials other than glass.

1.6 The test methods referenced in this guide are laboratory test methods conducted under specified conditions.

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

1.8 There is no comparable International Standards Organization Standard.

1.9 *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

E2141 Test Methods for Assessing the Durability of Absorptive Electrochromic Coatings on 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

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

E2355 Test Method for Measuring the Visible Light Transmission Uniformity of an Absorptive Electrochromic Coating on a Glazing Surface

3. Terminology

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

3.2 *Definitions of Terms Specific to This Standard:*

[1] This guide 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.

3.2.1 *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 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).

3.2.3 *colored state*—a descriptor for an EC coating 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).

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

3.2.5 *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.

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

3.2.7 *electrochromic (EC) glazing*—a device with an ECC consisting of several layers of electrochromic, 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.

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

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

3.2.10 *sealed insulating glass unit*—is defined in Test Method 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.

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

4. Significance and Use

4.1 This guide provides a recommended systematic sequence for using the referenced test methods for evaluating the durability of EC insulating glass units (IGUs) as described in section 1.2.[2,4] (See Appendix X1, Section X1.4.)

4.2 This guide provides a summary of the durability issues addressed by each of the series of standards that are necessary for assesing the durability of electrochromic coatings (ECCs) in insulating glass units (IGUs). When fully implemented in buildings in the U.S., ECCs in IGUs have the potential of significantly reducing our current energy consumption for all uses-not just buildings. IGUs with ECCs will, of necessity, have to be able to pass the applicable standards listed in Appendix X1, Section X1.4, as well as an ASTM standard on wind loading for IGUs. Passing these will not be sufficient because the operating temperatures of ECCs in IGUs can potentially be as high as 90°C at the center-of glass, whereas the highest temperature used in Test Method E2188 is 60°C . Listings of existing and proposed standards are given in Table 1 and in Appendix X1, Section X1.4.

5. Background

5.1 Durability is a critical requirement for an 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 guide is to provide a recommended sequence for assessing the durability of absorptive ECCs within sealed IGUs.

5.2 EC glazing perform a number of important functions in a building envelope including: minimizing the solar energy

[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.

TABLE 1 Recommended Sequence for Using the Referenced or Planned Test Methods or Practice to Address Questions about the Durability or Serviceability of ECCs within an IGU

Standard	Qualification or Durability Question Addressed
	Stability of the ECC within an IGU
E2355	Will the ECC in the IGU pass initial uniformity inspection and transmittance measurements in the colored and bleached states? This test method shall also be used to demonstrate if an acceptable uniformity is maintained after the specimens have been subjected to one or more of the accelerated life tests.
E2241	Can the ECC survive at least 50 000 current-voltage (coloring/bleaching) cycles over 5000 h at room temperature without a loss in performance below an acceptable level"?
E2240	Can the ECC survive at least 50 000 current-voltage (coloring/bleaching) cycles over 5000 h at the anticipated highest operating temperature of 90°C without a loss in performance below an acceptable level"?
E2141	Can the ECC survive 50 000 current-voltage (coloring/bleaching) cycles at 90°C in the presence of UV without a loss in performance below an acceptable level"?
	Assessing the Durability of the ECC within an IGU and of the Stability and Durability of the IGU
E2190	Will the IGU with the ECC pass the industry standard for the performance of IGUs?

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. Solar heat gain through an EC glazing is decreased because of two principal processes. Energy from the visible part of the spectrum is absorbed by an EC glazing in the colored state. In addition, infrared radiation is either absorbed and reflected by the EC glazing materials or is reflected by the transparent conducting oxide layers that are used for applying the coloring or bleaching potentials across the other layers in the EC glazing.

5.3 It is possible, but difficult to predict the time-dependent performance of EC IGUs from accelerated aging tests because of the reasons listed below. Users of this guide should be aware of these limitations when reviewing published performance results and their connection to durability.

5.3.1 The degradation mechanisms of EC IGUs materials and/or glazings are complex. In some cases, however, these mechanisms may be determined and quantified.

5.3.2 The external factors that affect the performance of EC IGUs are numerous and may be difficult to quantify. However, in some cases, the use, the environmental factors, and other information that influence performance may be known.

5.3.3 Fenestration units with tested ECCs may be different from those planned for use in service. Some companies have a database of in-service performance that can be compared to laboratory results.

5.4 Degradation factors (or stresses) for EC IGUs include the ion insertion and removal processes; temperature; solar radiation (especially UV); water vapor; atmospheric gases and pollutants; thermal stresses such as shock from sudden rain, as well as during the diurnal and annual temperature cycles; electrochemically induced stresses in the multilayer thin-film device; hail, dust, and wind; condensation and evaporation of water; and thermal expansion mismatches.[2,4] These factors may singularly or collectively limit the stability and durability of EC IGUs. Because the EC IGUs are expected to have the multilayer of coatings on one of the surfaces in the air space of double-pane or triple-pane IG units with an inert gas fill in the sealed space, many factors such as high humidity, atmospheric gases and pollutants, condensation and evaporation of water, and dust should not affect the durability of electrochromic coatings in IG units.[2]

5.4.1 Establishing test procedures from which EC IGU durability can be predicted and validated for in-service use is an extremely crucial element for the commercialization of EC IGUs. To reduce the number of accelerated test parameters that are required to predict the long-term performance of EC IGUs, accepted procedures or methods have not been established for testing EC glazings.[2] Because no uniformly accepted procedures or methods have been established for the real-time testing of EC IGUs and because manufacturers and users cannot wait 20 or more years for the real-time evaluation of each window design, accelerated life testing (ALT) methods, procedures, parameters, and evaluation must be used for assessing EC glazing stability.[2,4] These include *(a)* rapid but realistic current-voltage (I-V) cyclic tests emphasizing the electrical properties, *(b)* ALT parameters that are typically used in durability tests by standards organizations, *(c)* ALT parameters that are realistic for the intended use of large-area EC IGUs, and *(d)* how the ALT results must be related to real-time testing.[2] The purpose of this guide is to provide the recommended sequence for using the referenced ASTM test methods for assessing the durability of absorptive electrochromic coatings (ECCs) within sealed insulating glass units in which the ECC is on an inside glazing surface and of the preassembled permanently sealed IGUs that are at least 250 by 250-mm.

6. Procedure

6.1 Study the referenced test methods and practices. Devote special attention to the sections on scope, significance and use, and an overview of each test method. Note especially that the adopted standard Test Method E2141 addresses the broad scope of assessing the durability of electrochromic coatings in insulating glass units (IGUs).

6.2 Note that the expected in service environmental exposures for the EC glazing will range from temperature extremes from −30°C to 90°C at the center-of-glass, relative humidities of up to 95 %, and solar irradiance of up to 1200 W per square meter. For service lifetimes of up to 20 years, it is anticipated an EC glazing must survive 50 000 cycles from the bleached state as well as 5000 h under accelerated test conditions. These criteria dominate the rationale for the selection of the test conditions used in the referenced test methods and practices.

6.3 Note that the need for a series of standards, which will permit manufacturers of electrochromic coatings in insulating glass units (IGUs) to determine if their products are ready for the more comprehensive Test Method E2141 has resulted in the adoption of additional standards. These additional test methods may be defined as “qualification” standards, that is, if the product passes a rather simple, less expensive qualification test, then it is ready for the more-comprehensive scrutiny inherent in Test Method E2141.

6.4 Refer to Table 1 for a summary of the durability questions addressed from using each of the referenced methods and practices.

6.5 Evaluate what is already known about each particular EC glazing for which a service durability assessment needs to be made.

6.6 Revise the sequence of testing to fit the needs for assessing the durability of any particular absorptive ECC within an IGU.

6.7 Implement the revised sequence of testing.

7. Keywords

7.1 chromogenic glazing; durability; electrochromic windows; fenestration; insulating glass units; sealed insulating glass units

APPENDIX

(Nonmandatory Information)

X1. ADDITIONAL INFORMATION

X1.1 Acronyms Used in This and Related Test Methods

X1.1.1 ALT = accelerated life testing

X1.1.2 I-V = current-voltage

X1.1.3 ECC (s) = electrochromic coating(s)

X1.1.4 IG = insulating glass

X1.1.5 IGU (s) = insulating glass unit(s)

X1.1.6 IR = infrared (radiation)

X1.1.7 PTR = photopic transmittance ratio or $\text{transmittance}_{\text{bleached}}/\text{transmittance}_{\text{colored}}$

X1.1.8 TCO (s) = transparent conducting oxide(s)

X1.1.9 UV = ultraviolet (radiation)

X1.1.10 V = voltage

X1.2 Additional Useful Standards Related to This Standard

X1.2.1 ASTM Standards (Refer to Terminology G113 for a Description of General Terms):[3]

C1036 Specification for Flat Glass

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

C1172 Specification for Laminated Architectural Flat Glass

C1199 Test Method for Measuring the Steady State Thermal Transmittance of Fenestration Systems Using Hot Box Methods

E122 Practice for Calculating Sample Size to Estimate, with a Specified Tolerable Area, the Average for Characteristic of a Lot or Process

E546 Test Method for Frost Point of Sealed Insulating Glass Units

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

E1423 Practice for Determining the Steady State Thermal Transmittance of Fenestration Systems

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

X1.3 Additional Useful Definitions for Terminology Used or Referenced in This Standard

X1.3.1 *accelerated life testing*—a protocol that results in accelerated aging of materials or devices.

X1.3.2 *chromogenic glazing*—a glazing consisting of one or more layers of chromogenic materials, which are able to alter their optical properties in response to a change in ambient conditions such as illumination intensity, temperature, applied electric field, and so forth. The changeable optical properties include transmittance, reflectance, absorptance, and emittance.

X1.3.3 *counter electrode layer*—the ion storage material in an EC coating that serves as a reservoir for ions that can be inserted into or received from the electrochromic layer.

X1.3.4 *degradation factors*—conditions, imposed or natural, that influence or cause a degradation mechanism, effect, or mode.

X1.3.5 *electro-optic characterization*—the process of recording optical changes (transmittance, reflectance, absorptance, and so forth.) in an EC glazing as a function of electrical protocols (voltage, current).

X1.3.6 *electro-optic cycling*—the electrochemical cycling process of applying repetitive positive and negative voltages to an EC glazing for the purpose of reversibly changing the optical properties of the EC device from the bleached to the colored state.

X1.3.7 *optical photopic transmittance ratio*—the ratio of the bleached state transmittance (τ_b) to the colored state transmittance (τ_c) where τ_b and τ_c are both weighted by a spectral photopic response curve.

X1.3.8 *optical transmittance*—the ratio of the radiant energy transmitted by a body to the total radiant energy incident upon the body.

X1.3.9 *photodiode array spectrophotometer*—an optical detector system that uses an array of photodiodes coupled to CCDs to facilitate UV-VIS-NIR spectroscopic measurements.

X1.3.10 *sealed insulating glass unit*—a preassembled unit, comprising lites of glass, which are sealed at the edges and separated by dehydrated spaces(s), intended for vision areas of buildings. The unit is normally used for windows, window walls, picture windows, sliding doors, patio doors, or other types of fenestration.

X1.3.11 *spectral photopic response*—the relative response of the human eye in its light adapted state (daylight) to radiation of a given wavelength in the spectral region of ~410 to 720 nm.

X1.3.12 *specular transmittance*—the optical transmittance that does not include light with a diffuse component.

X1.3.13 *trapezoidal voltage profile*—the geometric shape generated by plotting the voltage versus time applied to an EC glazing with a slope in V/s up to a constant voltage and then a negative slope in V/s back to zero voltage.

X1.4 Additional Published Standards under the Jurisdiction of E06.22 (Task Group 22.05)

X1.4.1 ASTM Standards:[3]

E546 Test Method for Frost Point of Sealed Insulating Glass Units

E576 Test Method for Frost Point of Sealed Insulating Glass Units in the Vertical Position

E1887 Test Method for Fog Determination

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

E2269 Test Method for Determining Argon Concentration in Sealed Insulating Glass Units Using Gas Chromatography