



Standard Test Method for Accelerated Testing for Color Stability of Plastics Exposed to Indoor Fluorescent Lighting and Window-Filtered Daylight¹

This standard is issued under the fixed designation D 4674; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers an accelerated procedure intended to determine the resistance to color change of plastics in typical office environments, where overhead fluorescent light and window-filtered daylight are used for illumination, and where temperature and humidity conditions are in accordance with American Society of Heating, Refrigerating, and Airconditioning Engineers (ASHRAE) recommendations for workers' comfort.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Specific precautionary statements are given in Section 6.*

2. Referenced Documents

2.1 Specification for ASTM Standards:

D 1729 Practice for Visual Evaluation of Color Differences of Opaque Materials²

D 2244 Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates³

2.2 Other Document:

American Society of Heating, Refrigerating, and Airconditioning Engineers, Applications Handbook 1981, Section 1 on Comfort, Chapter 3.9⁴

3. Summary of Test Method

3.1 This test method provides for the exposure of specimens to the radiant energy from an array of eleven very-high output (VHO) cool, white fluorescent lamps and, simultaneously, to intermittent energy from two soda-lime glass-filtered fluorescent UV sunlamps. The extent of UV irradiation (nominal UV actinic exposure or UVAE) from both sources is determined

separately as the product of UV irradiance at the start of the test and exposure time, in Watt-hours/m² (W-h/m²).

3.1.1 The contribution of sunlamp irradiation to the total UV actinic exposure is maintained constant by adjusting the on/off cycle time of the sunlamps.

3.1.2 The average nominal sunlamp UV actinic exposure is set at 12 % of the value for the VHO lamps.

NOTE 1—Although office machines see some UV exposure due to sunlight, most originates from fluorescent lighting. The 12 % is an estimate of a representative office environment.

3.2 Color change is determined periodically throughout the course of the exposure by comparison of the exposed to the masked or unexposed specimens, using either visual or instrumental procedures.

3.3 The final color change should be evaluated in less than 24 h after the test is completed, preferably in less than 1 h, to eliminate possible misleading consequences of postactinic reaction. (Color change initiated by accelerated exposure may continue after removal of specimens from exposure to radiation.)

4. Significance and Use

4.1 This test method is intended to produce the color changes that may occur in plastics upon exposure to irradiation from typical office lighting by simulating these office conditions.

4.1.1 It is recognized that the rate of photodegradation of plastics will vary significantly due to factors such as processing conditions, initial color, pigment loading, the presence/type of flame retardants and other additives, etc. Consequently, correlation of accelerated test results with actual end-use performance must be determined individually for each resin system.

4.1.2 Variations in exposure time, temperature and humidity may also affect results.

5. Apparatus⁵

5.1 The test chamber shall be constructed of UV reflective aluminum with a clear, chromate conversion coating. An arched reflector with a radius of 330 mm serves as the chamber

¹ This test method is under the jurisdiction of ASTM Committee D-20 on Plastics and is the direct responsibility of Subcommittee D20.50 on Permanence Properties.

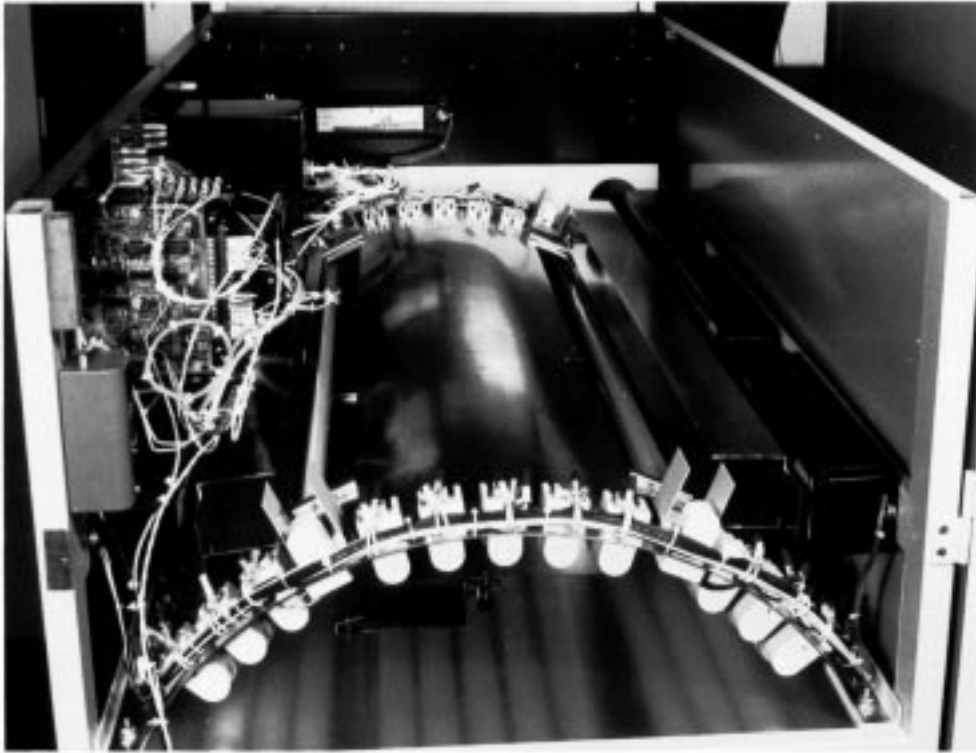
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² Annual Book of ASTM Standards, Vol 14.02.

³ Annual Book of ASTM Standards, Vol 06.01.

⁴ Available from the American Society of Heating, Refrigerating, and Airconditioning Engineers 1791 Tullie Circle Northeast, Atlanta, GA, 30329.

⁵ Apparatus available from Atlas Electric Devices Co., 4114 Ravenswood Ave., Chicago, IL 60613 has been found satisfactory.



NOTE 1—Inside view showing curved reflecting roof (tunnel) and fluorescent lamps. The two 40-W fluorescent sunlamps are on the upper portion of the reflecting tunnel directly above the soda-lime glass filters placed in the apertures in the tunnel. The eleven VHO fluorescent lamps are mounted on the underside of the tunnel. The sensor for the high-temperature thermostatic switch is below the center fluorescent lamp and at the right edge of the specimen drawer.

FIG. 1 Inside View Showing Curved Reflecting Roof (Tunnel) and Fluorescent Lamps

roof. The reflector also contains two apertures that hold soda-lime glass panels which filter the sunlamps. The vertical distance from the exposed surface of the specimen to the lamp surface shall be 140 ± 3 mm at the midpoint of the arch. See Figs. 1 and 2.

5.1.1 Eleven 1500-mA cool white VHO fluorescent lamps (CW)⁶ shall be mounted in three groups on the inner surface of the reflector. The angular spacing between lamps in each group shall be $8^\circ, 45$ min. See Figs. 1 and 2.

5.1.2 A 430-mA fluorescent sunlamp (FS)⁷ shall be mounted directly above each of the two apertures at a position $26^\circ 15$ min from the vertical plane intersecting the longitudinal axis of the test chamber. Each lamp must be mounted behind a soda-lime glass filter (2.4 ± 0.2 mm thick). (See Fig. 1, lamps 12 and 13).

5.2 The specimen table shall have the same reflecting surface as the lamp reflector. It shall have a vertical adjustment to control specimen-to-lamp distance. The table shall accom-

modate two specimen trays, each having an area of approximately 0.13 m^2 (630 by 210 mm) separated by a median containing a center port for the cosine receptor (light sensor) of the radiometer.

5.3 To assure uniform test conditions, it is important that all lamps shall be in accordance with 5.1.1 and 5.1.2. All 1500-mA lamps shall be cool white. Both 430-mA lamps shall be fluorescent F40T12UVB sunlamps.

5.4 The apparatus shall be used only in an environment which meets ASHRAE recommendations of 20 to 25.5°C ambient temperature and 40 to 50 % relative humidity.

5.4.1 The lamps and ballasts shall be forced-air cooled to maintain the air temperature in the test chamber between 30 and 40°C .

5.4.2 The apparatus shall be equipped with a thermostatic sensor that will cause the lamps to be turned off should the upper temperature limit in the specimen area be exceeded.

5.5 The apparatus shall be equipped with timing devices and time meters to control on-time for the 1500-mA lamps, to control on/off cycling for the 430-mA lamps, and to record total time of operation for each type of lamp.

5.6 The apparatus shall include a properly calibrated radiometer to measure irradiance in the exposure chamber. The light detector shall be located centrally in the exposure table; it shall have a bandpass from 250 to 400 nm and be a cosine response receptor.

⁶ A 1500-mA lamp is a cool white (CW) fluorescent lamp with a tubular bulb approximately 38 mm in diameter and 1220 mm in length, rated at 110 W and designated F48T12 CW/VHO, or its equivalent. F48T12CW/VHO Fluorescent Cool White Lamps, available from North American Philips Lighting Corp., Bloomfield, NJ 07003, have been found satisfactory.

⁷ A 430-mA lamp is a fluorescent sunlamp (FS) of similar dimension to the cool white lamp described in Footnote 5, rated at 40 W and designated as F40T12UVB, or its equivalent. F40T12UVB Fluorescent UV Sunlamps are also available from North American Philips Lighting Corp.

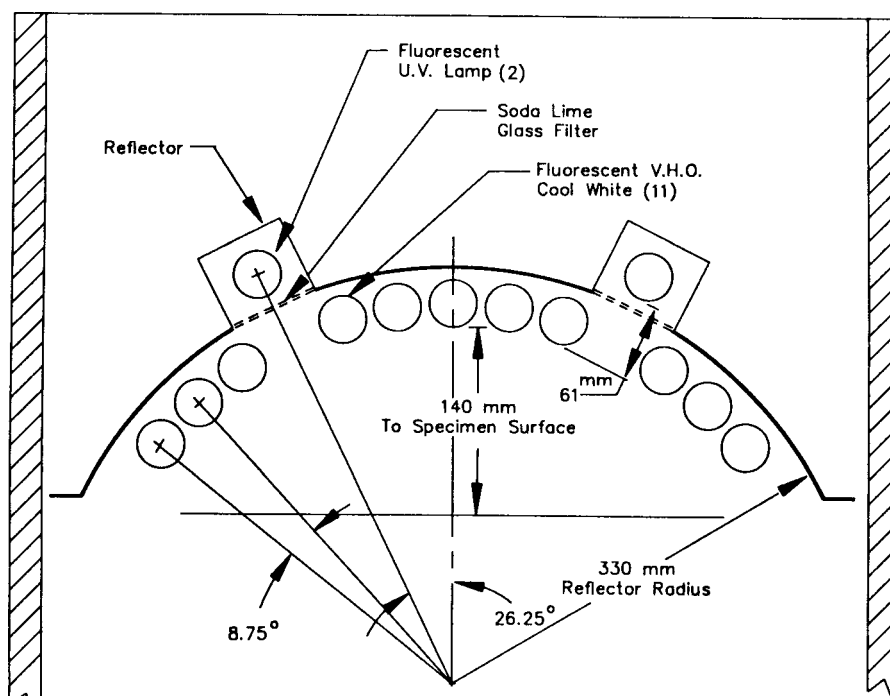


FIG. 2 Apparatus, Schematic Cross Section

6. Safety Precautions

6.1 Never look directly at the operating sunlamps unless wearing UV protective eyewear. The apparatus specified in Section 5 shall be constructed so that the operator will not be exposed to hazardous levels of UV radiation. Access to the lamp area shall be protected by safety switches that turn the lamps off prior to gaining access. The apparatus shall have a circuit breaker switch controlling electric power to the apparatus.

6.2 Sunlamps should be discarded when they are no longer suitable for this apparatus; they should not be used for any other purpose.

7. Test Specimens

7.1 The recommended specimen size is a rectangular flat piece 50 by 80 by 4 mm (maximum thickness). This size is adequate for visual or instrumental evaluation. Other specimen dimensions may be used by mutual agreement among the parties concerned but exposed surfaces should be coplanar.

7.2 It is recommended that one half of each test specimen be masked with aluminum foil, tightly wrapped to prevent exposure of the covered side. The entire specimen may be exposed if an unexposed control is used to judge color shift, or if the color of the test specimen is measured instrumentally and recorded prior to exposure.

7.2.1 Use of aluminum foil-masked specimens may result in a higher irradiance level due to increased reflectivity of the specimen area.

8. Preparation of Apparatus

8.1 Verify proper lamp function before starting any test.

8.2 Verify the UV irradiance level of each type of lamp before starting a test. Carry out verification of irradiance with

samples in place; otherwise reflectance of the bare aluminum tray will give erroneous results. Radiometer readings at the start of the test shall not be less than 8.0 W/m² for the 1500-mA lamps and 1.0 W/m² for the 430-mA lamps.

9. Conditioning

9.1 Specimen conditioning is unnecessary for this test beyond a visual inspection for uniformity of color and the absence of surface irregularities which could adversely affect color measurement.

9.2 Pre-age the lamps by leaving them on for a minimum of 48 h prior to initial test. Replace all of the lamps when the irradiance falls below the limits specified in 8.2.

10. Procedure

10.1 Make an initial color determination prior to loading specimens.

10.2 Open specimen drawer and load specimen trays. Arrange the specimens in rows beginning in the middle and leaving a minimum 25-mm empty border around the edge of the trays. Each tray will accommodate 21 to 22 samples of the 50 by 80-mm size recommended in 7.1.

10.2.1 Adjust the specimens or specimen table so that the surfaces of all test specimens are within 3 mm of being coplanar with the cosine receptor.

10.3 Close the specimen drawer and verify lamp irradiance level in accordance with 8.2.

10.3.1 Turn on both sets of lamps. After 20 min, turn off FS lamps and record the CW irradiance (radiometer reading) in W/m². Calculate the exposure time for the desired cool white UV Actinic Exposure (UVAE) as follows:

$$\text{CW Exposure, h} = \text{CW UVAE/CW Irradiance} \quad (1)$$

(Example: CW Exposure, h = 3240/10.8 = 300 h)

where:

3240 W-h/m² = example of an often-agreed-upon exposure, and

10.8 = radiometer reading.

10.3.2 Turn off the CW lamps and turn on the FS lamps. Record the radiometer reading (W/m²). Calculate the total FS lamp on-time as follows:

$$\text{FS On-time, h} = 12 \% \text{ CW UVAE/FS Irradiance} \quad (2)$$

$$\text{(Example: FS On-time, h} = (0.12)(3240)/2.0 = 194 \text{ h)}$$

where:

2.0 = radiometer reading for the FS lamps.

10.4 Calculate the off-time interval/cycle for the FS lamps by subtracting the FS on-time from the CW exposure time and dividing by the FS on-time.

$$\left(\text{Example: } \frac{300 - 194}{194} = \frac{106}{194} = 0.546 \text{ off-time h/cycle} \right) \quad (3)$$

10.4.1 Program the FS lamp cycling timer to a 1-h time-on interval/cycle.

10.4.2 Program the FS lamp timer to the off-time interval/cycle calculated in 10.4.

10.4.3 Replace the CW lamps if the total on-time for the FS exceeds the CW exposure time.

10.4.4 Do not add additional specimens once the test has begun.

10.5 Start the test at a time which will assure prompt color measurement when the test is completed.

10.5.1 The CW lamps should be on continuously throughout the entire exposure except for brief periods in which the samples are removed for color measurement in accordance with 10.6. Verify that the FS lamps maintain a reproducible cycle of 1 h on followed by the calculated time off.

10.5.2 Having determined and verified the test duration and FS cycle intervals, do not make adjustments in test/cycle time during the test. If lamps fail during the test, replace them and restart the entire test with new specimens.

10.5.3 Rotate specimens at time intervals equal to 25 ± 5 % of total test time by moving those in the innermost row (adjacent to median) to the outermost row of the same specimen tray. Move all remaining rows one row position closer to the median.

10.6 Evaluate the color change of the test specimens at several intervals throughout the course of the exposure in accordance with Method D 2244 or Practice D 1729. In addition to the initial reading, take color measurements when specimens are rotated and upon test completion. Additional color measurements may also be made.

NOTE 2—Colorfastness under these exposure conditions should be evaluated in terms of the lowest nominal UV actinic exposure required to produce a prescribed objectionable color change. Since discoloration is seldom linear with respect to dose or time, it is also important to observe the rate of discoloration. Plots of color change (for example, ΔE and its components, or both) versus exposure are useful. (See Appendix X1.)

10.6.1 Remove test specimens from the test chamber only after turning off the main power, thereby stopping the CW lamp countdown timer. The time required for color measurement during the course of the test shall not affect the total exposure time. To avoid post-actinic changes of samples taken

at intermediate points of the test cycle, complete color measurements as rapidly as possible. Following each color measurement, return test specimens to the appropriate locations and resume exposure until the test is completed.

10.6.2 If immediate evaluation of the final, post-exposure color change is not possible, refrigerate test specimens at – 15 to – 20°C to minimize possible effects of post-actinic reaction. In any case, make measurement within 5 days of test completion.

10.6.3 Terminology for describing the observed color change shall be established by mutual agreement among the parties concerned.

10.6.4 Instrumental evaluation of color difference in CIE L*a*b (CIE LAB) units in accordance with Method D 2244 shall be the preferred method for describing the color change between an unexposed control specimen and the exposed specimen or between the masked and unmasked areas of an exposed specimen, unless agreed upon by the parties involved.

NOTE 3—The preferred method uses reflectance measurement with integrating-sphere geometry, specular component included, and integration for CIE standard illuminant C and the 1931 (2°) standard observer; the UV component of the instrument source should be excluded. It should also be noted that significant differences in color measurements can occur, particularly in dark colors, when using different types of instruments.

11. Report

11.1 The report shall include the following:

11.1.1 Material identification and source (if known).

11.1.2 Exposure apparatus type.

11.1.3 Initial and final CW UV irradiance, W/m².

11.1.4 Initial and final FS UV irradiance, W/m².

11.1.5 Total exposure time, h.

11.1.6 Total FS on-time, h.

11.1.7 FS off-time interval.

11.1.8 *Basis for evaluation:*

11.1.8.1 Visual or instrumental, and

11.1.8.2 Masked or unexposed controls.

11.1.9 Exposure required to produce a prescribed color change or a plot of color change as a function of UV actinic exposure (W-h/m²) using either visual or instrumental measurement of color: J/m² = 2.78 × 10⁻⁴ W-h/m².

11.1.9.1 If instrumental color measurements are used, the type of equipment, any deviations from the requirements in Note 3, and color-difference equation used must be stated.

12. Precision and Bias

12.1 An interlaboratory test program was undertaken in 1986.⁸ Some laboratories reported five replicate results on four materials each in a light color (such as white) and a dark color (such as brown). CIE units (L, a, b) and ΔE values were measured by spectrometer at each time interval (T₀, T₂₅, T₅₀, T₇₅, and T₁₀₀). Due to data measurement problems occurring with three laboratories, statistical analysis was confined to only four laboratories.

12.2 Coefficients of variation (CV) for ΔE at 25 % of test cycle (T₂₅) were as follows:

⁸ Supporting data available from ASTM headquarters. Request RR: D20-1162.

Material		CV _R (%) ^A	CV _L (%) ^B
FRABS	light	11.4	14.4
	dark	45.6	43.3
Polycarbonate	light	5.2	5.2
	dark	44.6	76.8
Modified PPE	light	8.9	32.9
	dark	19.8	28.2
UV stabilized PPE	light	12.6	10.9
	dark	17.0	31.5

^A Within Labs.

^B Between Labs.

12.3 Coefficients of variation (CV) for ΔE at end of test cycle (T₁₀₀) were as follows:

Material		CV _R (%) ^A	CV _L (%) ^B
FRABS	light	13.6	13.7
	dark	8.9	13.9
Polycarbonate	light	7.0	6.8
	dark	88.9	9.6
Modified PPE	light	3.2	13.3
	dark	13.9	26.8
UV stabilized PPE	light	7.5	19.9
	dark	28.8	53.9

^A Within Labs.

^B Between Labs.

12.4 It should be noted that significant variation in the test data occurs early in the test cycle, as shown by the coefficients of variation in 12.2. This may be due to changes in the rate of discoloration for many materials near 25 % of the test. Therefore, one must use caution when evaluating materials for color

change using a short (<100 h) test cycle. A marked improvement is seen in the coefficients of variation for ΔE at the end of a full test cycle, as noted in 12.3. Therefore it is recommended that a full cycle, based on the example in Section 10, be used. Overall, at T₁₀₀ the largest variations were noted with those materials that had the smallest color change, for example, ΔE < 0.4. The most reproducible data occurred with those materials having a ΔE > 0.5. Although the reproducibility of the most color stable materials is poorer than the others, from a practical standpoint it is not considered significant because of the smallness of the data being measured and the instrument limitations.

12.5 The average ΔE and standard deviation at end of test (T₁₀₀) reported from each lab was as follows:

Material		Lab 1	Lab 2	Lab 3	Lab 4
FRABS	light	2.36 (±0.36)	1.88 (±0.39)	1.67 (±0.05)	2.14 (±0.12)
	dark	1.73 (±0.10)	1.54 (±0.19)	1.32 (±0.06)	1.26 (±0.13)
Polycarbonate	light	1.64 (±0.10)	1.66 (±0.05)	1.45 (±0.12)	1.45 (±0.15)
	dark	0.16 (±0.11)	0.28 (±0.29)	0.17 (±0.04)	0.11 (±0.02)
Modified PPE	light	9.94 (±0.36)	9.96 (±0.42)	8.46 (±0.14)	7.49 (±0.08)
	dark	1.16 (±0.20)	0.96 (±0.11)	0.79 (±0.04)	0.59 (±0.05)
UV stabilized PPE	light	4.35 (±0.41)	4.80 (±0.28)	3.12 (±0.23)	3.38 (±0.21)
	dark	0.65 (±0.19)	0.40 (±0.10)	0.23 (±0.01)	0.21 (±0.04)

12.6 Bias—Since no absolute method is available for comparison, no statement of bias can be presented for this test method.

12.7 No statement can be made about either precision or bias when visual measurement is used since the result merely states whether there is a conformance to the criteria for success specified in the procedure.

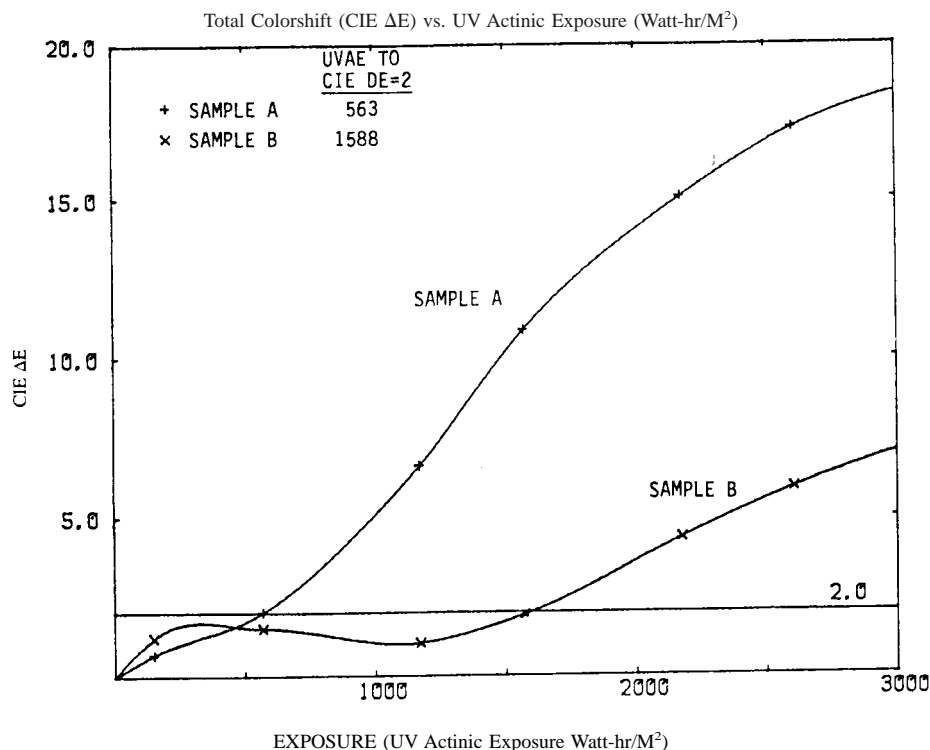


FIG. 3 Example of the Total Color Change vs. uv Actinic Exposure

APPENDIX**(Nonmandatory Information)****X1. JUDGING RELATIVE UV COLOR STABILITY BY THIS TEST METHOD**

X1.1 Color change due to UV photodegradation is known to be a nonlinear function of both UV irradiance and exposure time for many materials. Consequently, it is recommended that colorfastness be judged in terms of the nominal UV actinic exposure (irradiance \times exposure time) required to effect a prescribed objectionable color change, rather than the degree of color change obtained after an arbitrary exposure time.

X1.2 Fig. 3 shows an example of the total color change (CIE ΔE) versus UV actinic exposure ($W-h/m^2$) for two materials where an objectionable color change has been

arbitrarily defined as CIE $\Delta E = 2.0$.⁹ Material A exhibits an objectionable color change in $563 W-h/m^2$, while Material B did so after a UV actinic exposure of $1588 W-h/m^2$. Using the recommended criterion for judging relative color stability, Material B is superior to A by a factor of about 2.8 under these accelerated test conditions. For further interpretation of the results in terms of a possible correlation to real-world performance, see Section 4.

⁹ Fig. 3 was generated using software available from Laboratory MicroSystems, Inc., P.O. Box 336, Troy, NY 12181.

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