Standard Test Method for Luminance Ratio of a Fluorescent Specimen using a Narrow Band Source[1]

This standard is issued under the fixed designation E2630; 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 the instrumental measurement of the luminance ratio of a fluorescent coating or sheet sample when illuminated by a narrow band source.

1.2 This test method is generally applicable to any coating or sheeting material having combined fluorescent and reflective properties, where the fluorescence is activated by 405 nm light.

1.3 This test method is intended as a companion to Specification E2501 to support the development and specification of industrial coatings that are used in a system for detection of coating defects when inspected with the Specification E2501 light source. This test method establishes a quantitative measure of the optical property of a coating that correlates to its ability to enhance defect contrast under the specified inspection light source.

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

1.5 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D2805 Test Method for Hiding Power of Paints by Reflectometry

D4356 Practice for Establishing Consistent Test Method Tolerances (Withdrawn 2007)[3]

D5162 Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates

E179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials

E284 Terminology of Appearance

E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation

E1488 Guide for Statistical Procedures to Use in Developing and Applying Test Methods

E2501 Specification for Light Source Products for Inspection of Fluorescent Coatings

2.2 *Other Documents:*

ISO 10527:2007(E)/CIE S 014-1/E:2006 CIE Standard Colorimetric Observers[4]

CIE Publication 69:1987 Methods of characterizing illuminance meters and luminance meters: Performance, characteristics and specifications[4]

2.3 *SSPC:*

SSPC-SP 10/NACE No. 2 Near-White Blast Cleaning[5]

3. Terminology

3.1 The definitions contained in Guide E179, Terminology E284, and Practice E1164 are applicable to this test method.

3.2 The definitions for coating defects, discontinuity, holiday, and pinhole are contained in Practice D5162.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *luminance ratio, n*—luminance of the sample under a given narrow band 405 nm source divided by the luminance of a 25 % reflecting Lambertian diffuser under the same narrow band 405 nm source.

4. Summary of Test Method

4.1 This test method provides a procedure for measuring the luminance ratio of a fluorescent, reflective coating compared to

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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.

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

[4] Available from U.S. National Committee of the CIE (International Commission on Illumination), C/o Thomas M. Lemons, TLA-Lighting Consultants, Inc., 7 Pond St., Salem, MA 01970, http://www.cie-usnc.org.

[5] Available from Society for Protective Coatings (SSPC), 40 24th St., 6th Floor, Pittsburgh, PA 15222-4656, http://www.sspc.org.

a 25 % reflecting Lambertian diffuser, which is similar to steel grit blasted to an SSPC-SP 10/NACE No. 2 near-white metal blast.

4.2 This test method requires the use of a luminance meter, a narrow band 405 nm source and a calibrated non-fluorescent reflectance standard.

5. Significance and Use

5.1 The test method is suitable for the development, specification and quality control testing of fluorescent and non-fluorescent coatings that are intended to be inspected for defects under Specification E2501 illumination.

6. Apparatus

6.1 *Illuminator:*

6.1.1 The source shall have a peak wavelength of 405 nm (±1 nm), a symmetric unimodal distribution with a full width half maximum of 16 nm (±2 nm). The shape of the spectral distribution shall be triangular, Gaussian or isosceles trapezoidal where the width of the peak shall be less than one sixth the size of the base.

NOTE 1—A uniform or rectangular distribution does not meet this condition.

NOTE 2—An informational appendix (Appendix X1) is provided that briefly summarizes the reasons for the choices of tolerances in this test method.

6.1.2 The integrated irradiance over the wavelength range 490 to 760 nm shall be less than 0.01 % of the integrated irradiance over the wavelength range 380 to 760 nm.

NOTE 3—The light from 490 to 760 nm is typically from fluorescence generated in the light source. This light is heavily weighted by the luminous efficacy function, V(λ), resulting in large errors in the luminance ratio measurement. The fluorescence can be eliminated with a blue-green colored glass filter that has an internal transmittance at a reference thickness of 1 mm greater than 0.90 at 405 nm and less than 0.05 across the wavelength range of 500 to 680 nm.

6.1.3 The source shall produce a minimum irradiance sufficient to ensure a signal-to-noise ratio of 100 to 1 for the luminance meter described in 6.2.

NOTE 4—An irradiance of 10 W/m^2 is typically sufficient.

6.1.4 The illuminated area shall be at least twice the viewing area of the luminance meter. The minimum viewing area is specified in 6.2.4.

6.1.5 The source irradiance shall be stable to 1 % over the time frame of the measurements.

6.1.6 The illuminance on the sample surface shall be uniform within ±5 % of the average illuminance normal to the source. The illuminator may be collimated or not.

6.2 *Luminance Meter:*

6.2.1 The responsivity and range of the luminance meter shall be sufficient so that readings of both the non-fluorescent reflectance standard and the fluorescent sample are measured with a resolution of at least 1 part in 100.

6.2.2 If the luminance meter is filter based, the spectral responsivity of the luminance meter shall match that of the 1931 CIE Standard Photopic Observer. (ISO 10527:2007(E)⁄CIE S 014-1⁄E:2006) The individual spectral mismatch correction factors or the ratio of spectral mismatch correction factors with respect to the illuminator described in 6.1 shall be determined for the luminance meter to at least 1 part in 100 when measuring the non-fluorescent reflectance standard and the fluorescent sample.

NOTE 5—The ratio of the spectral mismatch correction factors may be determined by using a non-fluorescent reflectance standard calibrated under the source described in 6.1 and a fluorescent sample similar to the test sample, which are calibrated for luminance ratio under the source described in 6.1.

NOTE 6—An informational appendix (Appendix X1) is provided that briefly summarizes the method for calculating the spectral mismatch correction factors or the ratio of such.

6.2.3 If the luminance meter is spectrally based, the out-of-band stray light rejection shall be better than 1×10^{-5}.

6.2.4 The field-of-view of the luminance meter and the distance from the sample surface shall be such that the viewed region shall be larger than 2.5 cm^2 with no dimension smaller than 1.3 cm.

NOTE 7—The viewing area of the luminance meter depends on the field of view and the distance from the sample. The viewing area for a circular aperture is calculated by using the following equation:

$$viewing\ area = (\tan(v/2) \cdot d)^2 \cdot \pi / \cos(45°) \quad (1)$$

where:

v = field of view of the luminance meter and
d = distance between the luminance meter and the test sample.

6.2.5 The luminance meter shall be insensitive to the polarization of the light.

6.2.6 The linearity of the luminance meter over the range of measurements shall be within 1 %. Correction factors may be used to ensure a linear response.

6.2.7 The stability of the luminance meter over the duration of the measurements shall not vary more than 1 %.

6.2.8 The out-of-view sensitivity, described in CIE Publication 69, of the luminance meter shall be less than 0.5 %.

6.3 *Non-fluorescent Reflectance Standard:*

6.3.1 The non-fluorescent reflectance standard shall be calibrated in a 0°:45° geometry for luminous reflectance under the source described in 6.1with an expanded uncertainty (k = 2) of less than 1 %.

NOTE 8—The magnitude of the luminous reflectance of the non-fluorescent reflectance standard is somewhat arbitrary, because it is normalized to 0.25 in the calculations shown in 10.1. Typically, the magnitude of the luminous reflectance of the non-fluorescent reflectance standard is above 0.9 in order to have a larger signal-to-noise ratio.

6.3.2 The non-fluorescent reflectance standard shall have an integrated radiance over the wavelength range 490 to 760 nm less than 0.05 % of the integrated radiance over the wavelength range 380 to 760 nm under the illuminator specified in 6.1.

6.3.3 The non-fluorescent reflectance standard shall produce a diffuse distribution when illuminated.

7. Test Specimen

7.1 Prepare coating in accordance with Test Method D2805 for drawdown sample for hiding power by reflectometry.

7.2 Alternately, prepare by spraying or drawing down on a black substrate that has a maximum reflectance of 1 % and does not fluoresce.

7.3 The coating dry film thickness shall be within the manufacturers recommended range for the intended application.

8. Calibration and Standardization

8.1 The luminance meter shall be calibrated according to the manufacturer's specification. The individual spectral mismatch correction factors or the ratio of spectral mismatch correction factors with respect to the illuminator described in 6.1 shall be determined for the luminance meter when measuring the non-fluorescent reflectance standard and the fluorescent sample to at least 1 part in 100. (See Note 5.)

8.2 The non-fluorescent reflectance standard shall be calibrated as described in 6.3.1.

9. Procedure

9.1 Fig. 1 provides a schematic for the measurement alignment. The measurements shall be conducted in the dark such that the signal measured in 9.5 is less than 1 part of the signal measured in 9.4.

9.2 Position the illuminator described in 6.1 such that the angle between the direction of illumination and the normal to the specimen surface shall not exceed 2°. Position the luminance meter such that the angle between the direction of viewing and the normal to the specimen surface shall be 45 ± 2°.

NOTE 9—Fluorescent coatings inspected under a 405 nm illuminator enhance defect detection through two mechanisms: *(1)* enhanced contrast between the fluorescent coating and nonfluorescent substrate; and *(2)* uniform coating color and brightness regardless of the viewing angle. The second mechanism is important for inspecting the fluorescent coating along welds, in corners and on edges. Under white light inspection, defects in these areas are obscured by glare and shadows. With a 405 nm inspection light, dark spots are unambiguously interpreted as defects. This effect is primarily responsible for the increased productivity and accuracy reported by coatings inspectors in field trials. The luminance ratio at a 45° viewing angle correlates with this property better than that at a smaller viewing angle.

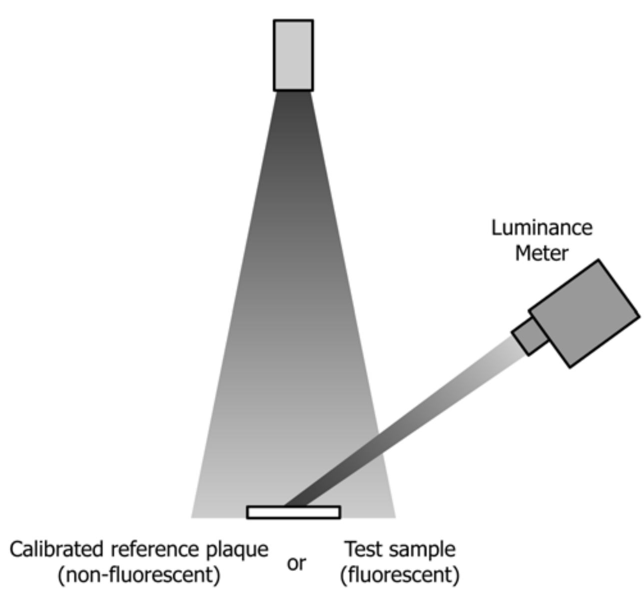

FIG. 1 A Schematic of the Measurement Alignment

9.3 The distance between the luminance meter and the sample surface shall be set such that the field-of-view defines a region of interest that is over illuminated by the illuminator according to 6.1.4.

9.4 Measure the non-fluorescent reflectance standard with the luminance meter.

9.4.1 Handle the samples carefully; avoid scratching or touching the area to be measured. To remove dust and lint use dry, filtered, pressurized nitrogen.

9.5 Block the illuminator such that the non-fluorescent reflectance standard is not illuminated and measure the dark non-fluorescent reflectance standard signal.

9.6 Position the fluorescent sample and measure the fluorescent sample with the luminance meter.

9.7 Block the illuminator such that the fluorescent sample is not illuminated and measure the dark fluorescent sample signal.

9.8 Calculate the luminance ratio using Eq 2 specified in 10.1

10. Calculation

10.1 For each fluorescent sample calculate the luminance ratio using the following equation:

$$R_L^B = \frac{(s - s_d)}{(s_P - s_{P,d})} \cdot \frac{F}{F_P} \cdot \frac{\rho^B}{0.25} \qquad (2)$$

where:

R_L^B = luminance ratio,
s = luminance signal for the fluorescent sample,
s_d = dark luminance signal for the fluorescent sample,
s_P = luminance signal for the non-fluorescent reflectance standard,
$s_{P,d}$ = dark luminance signal for the non-fluorescent reflectance standard,
F = spectral mismatch correction factor for the fluorescent sample under the illuminator,
F_P = spectral mismatch correction factor for the non-fluorescent reflectance standard under the illuminator, and
ρ^B = luminous reflectance of the non-fluorescent reflectance standard under the illuminator.

11. Report

11.1 The report shall contain the following information.

11.2 Sample identification including any commercial designation and manufacturer lot number.

11.3 Date of measurement.

11.4 Identification of the luminous reflectance of the non-fluorescent reflectance standard.

11.5 Description of apparatus.

11.5.1 Peak wavelength and full width half maximum of the illuminator.

11.5.2 Make and model number of luminance meter.

11.5.3 Distance between luminance meter and test specimen.

11.5.4 Filed-of-view of the luminance meter.

11.6 The luminance ratio.

12. Precision and Bias

12.1 *Precision*—The repeatability and the reproducibility of this test method is being determined and will be available on or before January 2011.

12.2 A preliminary estimate of precision has been made based on a test method sensitivity analysis. The repeatability standard deviation is expected to be less than 1.2 %. The reproducibility standard deviation is expected to be less than 13.5 %. These expectations are based on analysis of variability and ruggedness testing. The tolerance propagation equation from Practice D4356 was followed.

12.3 *Bias*—The bias of this test method is being determined and will be available on or before January 2011.

13. Measurement Uncertainty

13.1 The measurement uncertainty analysis shall provide a statement concerning each of the following components.

13.2 Signal resolution.

13.3 Spectral mismatch correction factor (for a filter based luminance meter).

13.3.1 The spectral mismatch correction factor is typically most sensitive to the excitation wavelength. The ratio of the spectral mismatch correction factors can be determined from calibrated samples but an analysis of the sensitivity to the excitation wavelength is still required because the peak wavelength of the illuminator used to calibrate the luminance meter may be different than the peak wavelength used to calibrate the samples.

13.3.2 The sensitivity of the spectral mismatch correction factor with respect to the excitation wavelength can be determined by a simulation which involves knowing the spectral responsivity of the luminance meter and the spectral power distribution of the light reflected from the nonfluorescent reflectance standard and the fluorescent sample. By shifting the spectral power distribution several nanometers toward the blue and red regions of the spectrum and recalculating the spectral mismatch correction factors a dependency on the excitation wavelength is estimated.

13.4 Excitation wavelength.

13.4.1 The luminance ratio is typically most dependent on the excitation wavelength.

13.4.2 The sensitivity of the luminance ratio with respect to the excitation wavelength can be determined experimentally by conducting the test method at a sequence of excitation wavelengths.

13.5 Illumination bandwidth.

13.6 Spectral out-of-band light (including fluorescence from the source).

13.7 Out-of-band stray light (stray light in a spectral based luminance meter).

13.8 Linearity of the luminance meter.

13.9 Out-of-field sensitivity of the luminance meter.

13.10 Stability of the illuminator and luminance meter over the duration of the measurements.

13.11 Geometric and alignment sensitivity of the illumination and luminance meter position.

13.12 Uniformity of the illuminator, non-fluorescent reflectance standard and fluorescent sample.

13.13 Temperature dependence of the illuminator, non-fluorescent reflectance standard, fluorescent sample and luminance meter.

13.14 Polarization dependence of the luminance meter.

14. Keywords

14.1 coating; fluorescence; holiday detection; inspection; luminance

APPENDIXES

(Nonmandatory Information)

X1. DETERMINATION OF MEASUREMENT TOLERANCES

X1.1 Following guidance in Guide E1488 and Practice D4356, an estimation of the test method tolerance was determined. Several factors that influence the test method result were analyzed for variability and ruggedness tests were conducted.

X1.2 Using the general tolerance propagation equation from Practice D4356 and sensitivity coefficients determined through simple derivatives, simulations, or experimental data an acceptable set of measurement tolerances was determined. Table X1.1 summarizes an analysis for a drawdown sample of a typical fluorescent primer used in coating shipboard tank using a filter based luminance meter. The estimated precision is the same as the test method tolerance.

X1.3 The largest component that contributes to the precision is the excitation wavelength of the source. The sensitivity of the luminance ratio with respect to the excitation wavelength was measured experimentally by conducting the test method at a sequence of excitation wavelengths. The results of these experiments are shown in Fig. X1.1.

X1.4 An analysis was completed for a luminance meter that is based on spectral data collection. Table X1.2 summarizes an analysis for a particular test sample using a spectral based luminance meter.

X1.5 For a luminance meter based on spectral data collection, a significant component is the out-of-band stray light that is detected inside the luminance meter. A single grating-array detector system typically cannot meet these requirements. For a single grating-array detector system stray light correction or rejection methods should be employed.

X1.6 The repeatability standard deviation was estimated by removing any components that would not change within repeatability conditions. The most significant components removed are the excitation wavelength and the bandwidth dependence. The repeatability standard deviation is then determined by dividing the test method tolerance by a coverage factor of 2.45. The coverage factor was taken from Practice D4356.

X1.7 The reproducibility standard deviation was estimated by using all the components and dividing the test method tolerance by a coverage factor of 2.45.

TABLE X1.1 Estimated Precision of Luminance Ratio Using a Filter Based Luminance Meter

Component	Symbol	Value	ΔX_i	$\partial R_L^B/\partial X_i$	Contribution
Sample signal	S	4.212 V	0.04 V	3.62 V^{-1}	0.0209
Sample dark signal	S_d	0.000 V	0.04 V	-3.62 V^{-1}	0.0209
Reference signal	S_P	0.3500 V	0.0035 V	-43.52 V^{-1}	0.0232
Reference dark signal	$S_{P,d}$	0.0000 V	0.0035 V	43.52 V^{-1}	0.0232
Spectral mismatch C_f sample	F	0.984	2 nm	0.091 nm^{-1}	0.0334
Spectral mismatch C_f reference	F_P	0.321	2 nm	0.366 nm^{-1}	0.5346
Standard luminance reflectance	r_B	0.97	0.003	15.70	0.0022
Excitation wavelength	λ_B	1.0	2 nm	-1.52 nm^{-1}	9.2808
Illumination bandwidth	$\Delta\lambda_B$	1.0	4.nm	0.37 nm^{-1}	2.1383
Spectral out-of-band light	λ_s	1.0	0.01	-51.91	0.2695
Linearity of detector	L	1.0	0.01	15.23	0.0232
Out-of-field sensitivity	O	1.0	0.005	15.23	0.0058
Voltmeter calibration	c_S	1.0	0.001	15.23	0.0002
Incident angle	$Ø$	0°	2°	-0.033 /°	0.0043
Viewing angle	θ	45°	4°	0.02 /°	0.0095
Luminance Ratio	R_L^B	**15.23**		**Estimated precision**	**4.98**
				Relative precision	**33 %**

TABLE X1.2 Estimated Precision of Luminance Ratio Using a Spectral Based Luminance Meter

Component	Symbol	Value	ΔX_i	$\partial R_L^B/\partial X_i$	Contribution
Sample signal	S	4.280 V	0.04 V	3.56 V^{-1}	0.0203
Sample dark signal	S_d	0.000 V	0.04 V	-3.56 V^{-1}	0.0203
Reference signal	S_P	1.090 V	0.01 V	-13.98 V^{-1}	0.0195
Reference dark signal	$S_{P,d}$	0.0000 V	0.01 V	13.98 V^{-1}	0.0195
Standard luminance reflectance	r_B	0.97	0.003	15.70	0.0022
Excitation wavelength	λ_B	1.0	2 nm	-1.52 nm^{-1}	9.2823
Illumination bandwidth	$\Delta\lambda_B$	1.0	4 nm	0.37 nm^{-1}	2.1386
Spectral out-of-band light	λ_s	1.0	0.01	-51.91	0.2695
Out-of-band stray light	S	1.0	1×10^{-5}	-7.78×10^4	0.6060
Linearity of detector	L	1.0	0.01	15.23	0.0232
Out-of-field sensitivity	O	1.0	0.005	15.23	0.0058
Voltmeter calibration	c_S	1.0	0.001	15.23	0.0002
Incident angle	$Ø$	0°	2°	-0.033 /°	0.0043
Viewing angle	θ	45°	4°	0.02 /°	0.0095
Luminance Ratio	R_L^B	**15.23**		**Estimated precision**	**4.98**
				Relative precision	**33 %**

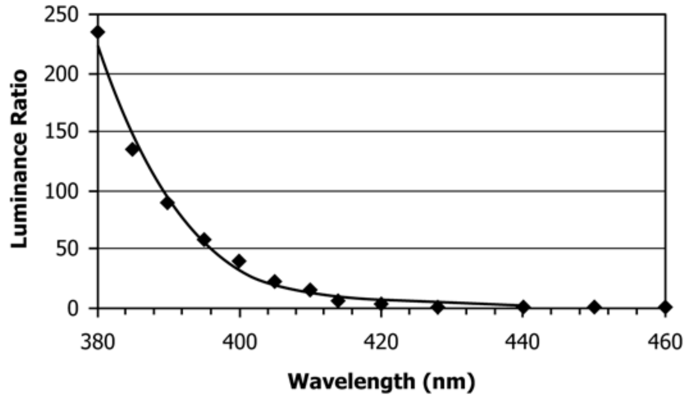

FIG. X1.1 The Luminance Ratio with Respect to Excitation Wavelength for a Fluorescent Primer to a Non-fluorescent Reflectance Standard

X2. INDIVIDUAL OR RATIOS OF SPECTRAL MISMATCH CORRECTION FACTORS

X2.1 Real photometers have a responsivity that is an approximation to the luminous efficacy function. These discrepancies can cause large errors when measuring a test source that is not similar to the calibration source.

X2.2 Determination of Spectral Mismatch Correction Factors:

X2.2.1 In order to determine the spectral mismatch correction factors the spectral responsivity of the photometer, $s(\lambda)$, the spectral distribution of the calibration source, $S_s(\lambda)$, and the spectral distribution of the test source are required, $S_t(\lambda)$.

X2.2.2 The spectral mismatch correction factor is calculated by using the equation,

$$F = \frac{\int_\lambda S_s(\lambda)s(\lambda)d\lambda}{\int_\lambda S_s(\lambda)V(\lambda)d\lambda} \cdot \frac{\int_\lambda S_t(\lambda)V(\lambda)d\lambda}{\int_\lambda S_t(\lambda)s(\lambda)d\lambda} \quad \text{(X2.1)}$$

The integrals can be approximated by summations. The first fraction removes the weighted corrections of the calibration source which is typically CIE illuminant A for luminance meters. The second fraction adds the corrections due to the test source. For this test method the test source is narrow band; therefore, the spectral mismatch correction factors should be calculated from 1 nm data.

X2.3 Determination of the Ratio of Spectral Mismatch Correction Factors:

X2.3.1 An alternate method of determining the ratio of spectral mismatch correction factors is to use a non-fluorescent reflectance standard calibrated for luminous reflectance under the source described in 6.1, ρ^B, and a fluorescent sample very similar to the test sample, which are calibrated for luminance ratio under the source described in 6.1, $R_L{}^B$.

X2.3.2 By measuring the luminance and dark signal of the non-fluorescent reflectance standard, S_P and $S_{P,d}$, and the luminance and dark signal of the fluorescent sample, S and S_d, under the source described in 6.1, the ratio of the spectral mismatch correction factors is calculated by using the equation,

$$\frac{F}{F_P} = \frac{(s_P - s_{P,d})}{(s - s_d)} \cdot \frac{0.25}{\rho^B} \cdot R_L^B \quad \text{(X2.2)}$$