Designation: E1349 – 06 (Reapproved 2013)

Standard Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional (45°:0° or 0°:45°) Geometry[1]

This standard is issued under the fixed designation E1349; 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 reflection properties and color of object-color specimens by use of a spectrophotometer or spectrocolorimeter with a bidirectional optical measuring system, such as annular, circumferential, or uniplanar 45:0 or 0:45 geometry.

1.2 This test method is generally suitable for any non-fluorescent, flat object-color specimen. It is especially recommended for measuring retroreflective specimens and specimens of intermediate gloss.

1.3 Procedures required for the measurement of fluorescent object color are given in Practice E991 and Practice E2153.

1.4 Procedures required for the measurement of color using filter colorimeters are contained in Test Method E1347 and this standard does not address those instruments.

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]

D2244 Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates

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

E284 Terminology of Appearance

E308 Practice for Computing the Colors of Objects by Using the CIE System

E694 Specification for Laboratory Glass Volumetric Apparatus

E805 Practice for Identification of Instrumental Methods of Color or Color-Difference Measurement of Materials

E991 Practice for Color Measurement of Fluorescent Specimens Using the One-Monochromator Method

E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation

E1345 Practice for Reducing the Effect of Variability of Color Measurement by Use of Multiple Measurements

E1347 Test Method for Color and Color-Difference Measurement by Tristimulus Colorimetry

E1767 Practice for Specifying the Geometries of Observation and Measurement to Characterize the Appearance of Materials

E2153 Practice for Obtaining Bispectral Photometric Data for Evaluation of Fluorescent Color

E2214 Practice for Specifying and Verifying the Performance of Color-Measuring Instruments

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions contained in Guide E179, Terminology E284, Practice E1164, Practice E1767, and Practice E2214 are applicable to this test method.

4. Summary of Test Method

4.1 This test method provides a procedure for measuring the reflectance factors of reflecting object-color specimens by using a spectrophotometer or spectrocolorimeter equipped with a bidirectional optical measuring system.

4.2 When the specimens exhibit directionality, and an instrument with uniplanar geometry is used, information on directionality may be obtained by measuring the specimens at more than one rotation angle, typically at two angles 90° apart as described in Practice E1345. When such information is not required, these measurements may be averaged, or an instrument with annular or circumferential geometry may be used. However, even with annular or circumferential influx or efflux optics, some of the variability induced by specimen — optical system interactions may remain and the application of the methods in Practice E1345 may help to further reduce those measurement errors.

[1] This test method is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.02 on Spectrophotometry and Colorimetry.

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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.

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4.3 This test method includes procedures for standardizing the instrument or verifying its standardization, and for selecting specimens suitable for precision measurement.

4.4 Most modern spectrometers have the capacity to compute the color coordinates of the specimen immediately following the measurement. When this is the case, the user must preselect the color system, observer, and illuminant (see Practice E308, Procedure section).

5. Significance and Use

5.1 The most direct and accessible methods for obtaining the color coordinates of object colors are by instrumental measurement using spectrophotometers or spectrocolorimeters with either hemispherical or bidirectional optical measuring systems. This test method provides procedures for such measurement by spectrophotometry using a bidirectional (0:45 or 45:0) optical measuring system. The method for color and color difference measurement using filter colorimeters is contained in Test Method E1347.

5.2 This test method is especially suitable for measurement of the following types of specimens for the indicated uses (see also Guide E179 and Practice E805):

5.2.1 Object-color specimens of any gloss level for color assessment.

5.2.2 Object-color specimens with physically flat, smooth surfaces from which to obtain data for use in computer colorant formulation.

5.2.3 Retroreflective specimens.

NOTE 1—To ensure inter-instrument agreement in the measurement of specimens with intermediate gloss, for formulation, or of retroreflective specimens, significantly tighter tolerances than those given in Practice E1164, Influx and Efflux Conditions, 45°:Normal (45:0) and Normal:45° (0:45) Reflectance Factor section, may be required for the instrument angles of illumination and viewing. Information on the required tolerances is being developed.

5.3 This test method is not recommended for measurement of specimens with bare metal surfaces for color assessment, for which the use of hemispherical measurement geometry, as with an integrating-sphere type instrument, is preferable (see Guide E179).

6. Apparatus

6.1 *Spectrophotometer or Spectrocolorimeter,* designed for the measurement of color coordinates of reflecting specimens by use of 45:0 or 0:45 geometry with annular, circumferential, or uniplanar illumination or viewing.

6.2 *Standardization Materials,* either supplied by the instrument manufacturer or obtained separately, as follows: (See Practice E1164, Standardization and Materials Standards section.)

6.2.1 *White Standard of Bidirectional Reflectance Factor (mandatory)*—(A standard of hemispherical reflectance factor is not suitable and should not be used.)

6.2.2 *Standardization Materials,* (*1*) for setting or verifying zero on the reflectance scale; (*2*) for verifying the wavelength scale; and (*3*) for evaluating stray light (optional).

6.2.3 *Verification Standards (recommended)*—(See Practice E1164, Standardization and Material Standards, System Verification section.)

NOTE 2—If retroreflective specimens are to be measured, the set of verification standards should include appropriate retroreflective product standards.

7. Test Specimen

7.1 For highest precision and accuracy, select specimens with the following properties:

7.1.1 High material uniformity and freedom from blemishes in the area to be measured.

7.1.2 Opaque specimens that have at least one plane surface; translucent specimens that have two essentially plane and parallel surfaces and that have a standard thickness, when one is specified (see Practice E1164, Test Specimens section).

7.2 If specimens exhibit directionality, use appropriate procedures (see 9.7) and calculations (see 10.1.1, Practice E1164, Test Specimens section, and Practice E1345).

8. Standardization and Verification

8.1 Standardize or verify the calibration of the following: (See Practice E1164, Standardization and Material Standards section.)

8.1.1 Zero setting of the reflectance scale (mandatory),

8.1.2 Wavelength scale (recommended), and

8.1.3 Stray-light level (optional).

8.2 Standardize the full-scale value of the reflectance scale of the instrument by use of the white reflectance standard (mandatory). Follow the instrument manufacturer's instructions.

8.3 Verify the accuracy of the instrumental data by measurement of a series of verification standards (recommended). (See Practice E1164, Standardization and Material Standards section.)

9. Procedure

9.1 When required, select the color scales, observer, and illuminant for the computation of color coordinates (see Practice E308, Procedure section).

9.2 Select other options, such as wavelength range and interval, when required. Follow instrument manufacturer's instructions or specified procedures.

9.3 If the specimen is translucent, select specified black or white backing material. (See Practice E1164, Test Specimens section, for further instructions on measuring translucent specimens.)

9.4 Handle the specimen carefully; avoid touching the area to be measured. When necessary, clean the specimen by using an agreed procedure.

9.5 Place the specimen, with backing material when required, against the measurement port of the instrument.

9.6 Measure the specimen, following the instrument manufacturer's instructions.

9.7 If the specimen exhibits directionality and the instrument has uniplanar geometry, measure the specimen at two

TABLE 1 E694 Compatible Precision Results

Color	L*			a*			b*		
	Grand Mean	r	R	Grand Mean	r	R	Grand Mean	r	R
A	82.60	0.41	0.60	-0.21	0.10	0.19	-0.38	0.09	0.48
B	55.79	0.23	0.33	-0.21	0.08	0.13	-0.44	0.09	0.34
C	56.02	0.24	0.49	-2.48	0.08	0.14	1.79	0.08	0.37
D	26.24	0.26	0.40	-0.30	0.22	0.24	0.54	0.18	0.28
E	40.49	0.18	0.58	30.32	0.19	0.36	5.30	0.20	0.85
F	34.87	0.23	1.07	56.32	0.26	0.61	42.32	0.55	1.73
G	65.84	0.38	1.07	40.54	0.26	1.31	64.87	0.36	1.31
H	84.08	0.21	1.04	-4.53	0.20	0.86	86.70	0.24	1.43
I	50.97	0.28	0.42	-34.70	0.25	1.00	14.19	0.15	1.03
J	51.44	0.36	0.46	-34.99	0.27	1.00	17.35	0.13	1.11
K	49.48	0.22	0.46	-12.71	0.15	1.08	-33.52	0.15	0.79
L	8.66	0.21	0.68	25.25	0.62	1.49	-35.35	0.43	1.24

rotation angles 90° apart (see also Practice E1345), usually parallel and perpendicular to the machine or processing direction, or use another specified procedure.

9.8 Transcribe the data required for the report, when not printed by the instrument.

10. Calculation

10.1 Perform any desired calculations of color coordinates that are not made automatically by the instrument (see Practice D2244 and Practice E308).

10.1.1 When specimens exhibiting directionality are measured at two or more rotation angles with instruments using uniplanar geometry, average the instrumental data at all rotation angles measured if information on directionality is not required.

11. Report

11.1 Report the following information:

11.1.1 Specimen description (see Practice E1164, Report section), and

11.1.2 Date of measurement.

11.1.3 *Instrument measuring geometry:*

11.1.3.1 45°:0° or 0°:45° illuminating and viewing geometry,

11.1.3.2 Annular, circumferential, or uniplanar geometry, and

11.1.3.3 Number and angular distribution of multiple illumination or viewing beams.

11.1.4 Instrument parameters as selected in 9.1 – 9.3, and

11.1.5 Measurement results, in the form of tables of reflectance factor versus wavelength or color-scale values.

11.1.5.1 For specimens exhibiting directionality measured at two or more rotation angles with instruments using uniplanar geometry, report individual measurements and corresponding specimen orientations when information on directionality is required; or report the average measurements when such information is not required.

12. Precision and Bias[3]

12.1 Data for the precision and bias of this test method have been determined from a combination of laboratory readings and data in the public domain. In general, the precision and bias for this test method are expected to be approximately the same as those reported in Practice E1164.

12.2 Laboratory test data came from 16 instruments in 9 different models, each used to collect 3 replicate readings of 12 ceramic color standards. The results of the analysis can be obtained from ASTM International headquarters. Table 1 gives the repeatability and reproducibility of the 12 colors.

12.3 Bias was determined by comparing the 576 readings to the values supplied for this set of materials by the National Physical Laboratory, Tedding, United Kindgom. For these colors the root-mean-square bias for L* is 0.28, for a* is 0.52, and for b* is 0.65. This translates into an RMS CIELAB color difference of about 0.8 units. Expected bias should be less than or equal to this quantity.

12.4 Based on the data reported in 12.1 – 12.3, the following conclusions can be drawn. First, the precision and bias of color measurement is not independent of the color of the material. Within that constraint, a conservative statement of precision is: The repeatability standard deviation has been determined to be 0.4 L* units, 0.3 a* units and 0.6 b* units. The reproducibility standard deviation has been determined to be 1.1 L* units, 1.3 a* units and 1.7 b* units. Using these 95 % limits as the expected ranges of the difference in color between any two determinations a further statement can be concerning the precision of 0°:45° spectrocolorimetry. The repeatability of two determinations should be considered suspect if the readings differ by morel than 0.8 CIELAB ΔE^*_{ab} units. Similarly the reproducibility of two determinations between two labs or two different instruments should be considered suspect if they differ by more than 2.4 CIELAB ΔE^*_{ab} units.

12.5 Reproducibility was determined by reviewing six reports from the Collaborative Reference Program. Reports 113, 117, 119, 120, 121, and 122 were selected. In these studies sets of three painted papers are distributed to participants. The color of the papers are measured and reported. The report separates participants by instrument geometry. The portion of the study returning measurement data for 45°:0° geometry was extracted. Only laboratories that were considered by the CRP to be representative of the population were included. There were between 50 and 52 laboratories included for each report. Six studies with three colors each were analyzed using the multivariate statistical methods detailed in Practice E2214. Plots of

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:E12-1001.

TABLE 2 Reproducibility Results

Collaborative Reference Program Sets — 45° : 0° Geometry				
Sample Set	Sample A	Sample B	Sample C	T^2 (99 %)
113	0.6 RP 6.9 / 6.5	0.6 RP 6.9 / 6.4	1.0 RP 6.8 / 6.7	13.1
117	2.7 Y 8.4 / 7.4	2.8 Y 8.5 / 7.3	3.1 Y 8.5 / 7.2	13.1
119	8.1 YR 6.8 / 9.2	8.2 YR 6.9 / 9.2	7.9 YR 6.9 / 9.1	13.1
120	1.1 YR 5.4 / 4.2	1.2 YR 5.3 / 4.3	1.3 YR 5.3 / 4.0	13.1
121	2.1 YR 5.4 / 5.8	2.5 YR 5.4 / 5.9	2.4 YR 5.6 / 5.7	13.1
122	8.1 B 3.2 / 2.8	7.5 B 3.2 / 3.90	7.2 B 3.2 / 3.0	13.1

the probability contours and CIE 94 color tolerances are included in the Appendix. Table 2 gives the approximate Munsell notation for the colors and the Hotellings T^2 statistic which, following Practice E2214, describes the 99 % confidence interval for the grand mean. The raw data and other statistical parameters, such as the variance-covariance matrix are included in a research report on file with ASTM Headquarters.

13. Keywords

13.1 bidirectional geometry; color; reflectance; spectrocolorimeter; spectrometer; spectrophotometer

APPENDIX

(Nonmandatory Information)

X1. PLOTS OF CIELAB a*-b* FOR THE CRP REPORTS 113

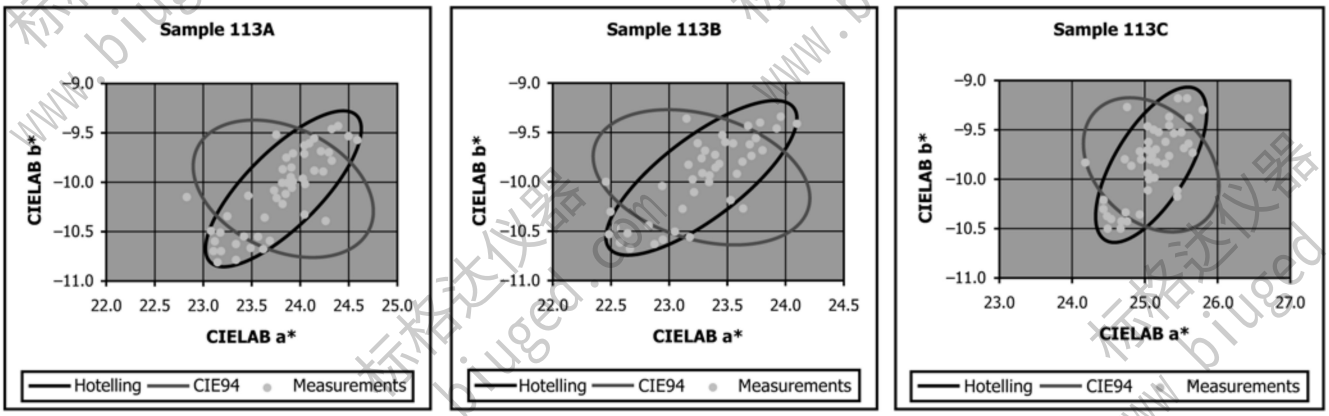

FIG. X1.1 Plots of CIELAV a*-b* for the CRP Reports 113

X1.1 These plots (see Fig. X1.1) illustrate the difference between the area enclosed by the Hotelling's 99 % confidence interval and the equivalent area enclosed by the CIE94 tolerance at the location of the grand mean.

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