Designation: E3040 – 16

Standard Practice for Evaluation of Instrumental Color Difference with a Gray Scale[1]

This standard is issued under the fixed designation E3040; 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 Test Method D2616 describes a painted gray scale and the procedure to be used in the visual evaluation of color differences on non-self-luminous materials by comparison to this scale. This practice provides an alternative method of obtaining a similarly valued result by an instrumental method.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard, except that the test results of this test method are converted by the calculations to an arbitrary visual scale defined by Test Method D2616, whose units are called GS_C (Gray Scale for Change in Color).

1.3 *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

D2616 Test Method for Evaluation of Visual Color Difference With a Gray Scale

E284 Terminology of Appearance

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

E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation

2.2 *ISO Standards:*[3]

ISO 105-A05 Textiles—Tests for Colorfastness—Part A05 Instrumental assessment of change in colour for determination of grey scale rating

2.3 *AATCC Standards:*[4]

AATCC Evaluation Procedure 7 Instrumental Assessment of the Change in Color of a Test Specimen

2.4 *JIS Standards:*[5]

JIS L 0809 Instrumental determination of colour fastness — Change in colour and staining

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of appearance terms in Terminology E284 are applicable to this test method.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *color change, n*—a change in color of any kind whether in lightness, hue, or chroma or any combination of these, discernible by comparing the test specimen with a corresponding untested specimen.

3.2.2 *gray scale grade, GS_C, n—for color change*, the numerical value that is assigned to the change in color of a test specimen as compared to an original or untreated specimen.

4. Summary of Test Method

4.1 The color of a specimen that has been submitted to a test whose severity is evaluated by change in color, and an identical untreated specimen, are measured spectrophotometrically and both of their colors evaluated by conventional means. The conventional color difference attributes are converted to a Gray Scale for Color Change by a series of calculations.

4.2 This practice is similar to the following three international methods: AATCC Evaluation Procedure 7, ISO 105-A05, and JIS L 0809.

[1] This practice is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.04 on Color and Appearance Analysis.

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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] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

[4] Available from American Association of Textile Chemists and Colorists (AATCC), P.O. Box 12215, Research Triangle Park, NC 27709-2215, http://www.aatcc.org.

[5] Available from Japanese Standards Association (JSA), Mita MT Bldg., 3-13-12 Mita, Minato-ku, Tokyo 108-0073, Japan, http://www.jsa.or.jp.

5. Significance and Use

5.1 The gray scale grade GS_C is useful to evaluate the color difference of any pair of colors that have been subjected to a test whose severity of result is nominated by color difference of the treated member to the untreated member. This includes, but is not limited to, scrub tests, exterior exposures, crocking tests, blocking tests, certain abrasion tests, and color transfer tests.

5.2 A major advantage of the instrumental method of obtaining gray scale grades is that under the visual method substantial screening and training of the operators in visual color assessment is required. No such burden is placed on the operators in this instrumental method.

5.3 The method is usually not used for staining tests which have their own gray scale for staining.

6. Apparatus

6.1 *Spectrophotometer,* having one of the three qualified geometries that are listed in Practice E1164. These geometries include: bidirectional (more familiarly called 0°/45° or 45°/0°), or hemispherical specular included, or hemispherical specular excluded geometries.

6.2 In the absence of any reason for choosing one over the other, hemispherical specular included geometry is most appropriate for the type of measurements that are made in connection with this standard.

7. Sampling, Test Specimens, and Test Units

7.1 The specimen pairs used in this practice are nearly always a pair of identical specimens where one member of the pair has been subjected to a test whose severity of result may be quantified by a change in color.

7.2 The practice is based upon a visual method D2616 of assessing the degree of this color change. The precision of the visual method is such that the gray scale grade is reported to the nearest half-unit on a scale of five to one. This method is designed to emulate the results of Test Method D2616 and as such is reported in these same half-units.

8. Calibration and Standardization

8.1 Maintain the spectrophotometer in a state of calibration. Standardize the spectrophotometer in accordance with the manufacturer's instructions, or follow the standardization practices of Practice E1164.

9. Procedure

9.1 Measure the color of the reference specimen and calculate the CIELAB L^*, a^*, b^*, C^* and h values using the data for the 10° observer and for illuminant D65.

9.2 Measure the color of the test specimen which has been subjected to the colorfastness test and make the same colorimetric calculations as done for the reference specimen. Then make the calculations as described in Annex A1.

10. Calculation or Interpretation of Results

10.1 A complete description of the calculations, the symbols and subscripts used in them, is given in Annex A1 of this method.

10.2 The results of the method derive GS_C values that are in half-steps between five and a value of unity. These values form a scale of discrete steps. An alternative continuous scale in Table A1.1 is equivalent and may be used at the user's option. The rounded value GS_C may be used as an index in the left-hand column to look-up the equivalent alternative continuous value in the right-hand column.

11. Report

11.1 Report the following information:

11.1.1 A complete description of the test pair and the treatment being evaluated by the destructive test;

11.1.2 The calculated value of GS_C calculated in connection with this sample pair;

11.1.3 The make, model, and serial number of the spectrophotometer used to make the spectral measurements, and the geometry of the instrument, bidirectional or hemispherical. If the geometry is hemispherical, state whether specular included or specular excluded mode was employed;

11.1.4 A statement that D65 and the 10° Observer were used to calculate the conventional colorimetric values, or, if a custom illuminant-observer was employed, which one, and a justification for that deviation from the standard method.

12. Precision and Bias

12.1 *Precision*—The practice does not in itself contribute to uncertainty of measurement, but rather converts the scale of the result, and with it the certainty, from that of CIELAB to GS_C.

12.2 *Bias*—No information can be provided about the bias of the test method for measuring GS_C because no material having an accepted reference value is available.

13. Keywords

13.1 color difference; gray scale; instrumental color-difference

ANNEX

(Mandatory Information)

A1. SYMBOLS AND CALCULATIONS

A1.1 Symbols

A1.1.1 The following subscripts are used in connection with the symbols of A1.1.2.

ab nominates that the scripted symbol is associated with the CIELAB color-difference equation (see Practice D2244).

F nominates that the scripted symbol is a special-case color difference component for Gray Scale for change in color, and thus differs in value from its CIELAB counterpart.

K nominates that the scripted symbol has been chroma corrected, and thus differs in value from its CIELAB counterpart.

M nominates the mean value of the scripted symbol between the test specimen and the reference specimen.

R nominates that the scripted symbol is associated with the reference specimen.

T nominates that the scripted symbol is associated with the test specimen.

A1.1.2 The following symbols are used in the calculations:

D = a place-holder for a chroma correction coefficient

h = a hue angle; as used in these equations the values are always in degrees, never radians. 2π radians are equal to 360 degrees.

x = a place-holder for a calculated exponent in the special ΔE equations

ΔC = chroma difference

ΔE = total color-difference

ΔH = hue difference

ΔL = lightness difference

G = a place-holder for the unrounded value of the color difference

A1.2 Calculations

A1.2.1 The following instructions define the calculations:

A1.2.1.1 Calculate L^*, a^*, b^*, h_{ab}, and C^*_{ab} of both the reference and the trial specimens in accordance with Practice E308, or Practice D2244, whose instructions are identical to each other.

if $Abs\ (h_{ab,T} - h_{ab,R}) \leq 180$ then

$$h_M = (h_{ab,T} + h_{ab,R})/2$$

else

if $Abs(h_{ab,T} + h_{ab,R}) < 360$ then

$$h_M = (h_{ab,T} + h_{ab,R})/2 + 180$$

else

$$h_M = (h_{ab,T} + h_{ab,R})/2 + 180$$

end if

end if

if $Abs(h_M - 280) \leq 180$ then

$$x = [(h_M - 280)/30]^2$$

else

$$x = [(360 - Abs\ (h_M - 280))/30]^2$$

end if

$$\Delta L^* = L^*_{ab,T} - L^*_{ab,R}$$

$$\Delta C^*_{ab} = C^*_{ab,T} - C^*_{ab,R}$$

$$C_M = (C^*_{ab,T} + C^*_{ab,R})$$

$$D = (\Delta C^*_{ab} \cdot C_M \cdot e^{-x})/100$$

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

$$\Delta H^*_{ab} = [(\Delta E^*_{ab})^2 - (\Delta L^*)^2 - (\Delta C^*_{ab})^2]^{1/2}$$

$$\Delta C_K = \Delta C^*_{ab} - D$$

$$\Delta H_K = \Delta H^*_{ab} - D$$

$$\Delta C_F = \Delta C_K/[1 + (10 \cdot C_M/1000)^2]$$

$$\Delta H_F = \Delta H_K/[1 + (20 \cdot C_M/1000)^2]$$

$$\Delta E_F = [(\Delta L^*)^2 + (\Delta C_F)^2\ (\Delta H_F)^2]^{1/2}$$

if $\Delta E_F \leq 3.4$ then

$$G = 5 - \Delta E_F/1.7$$

else

if $\Delta E_F \leq 16.15$ then

$$G = 5 - Log_2(\Delta E_F/0.85)$$

else

$$G = 1$$

end if

end if

$$GS_C = [Int(2 \cdot G + 0.5)]/2$$

A1.2.1.2 *Gray Scale Color Change Table*—See Table A1.1.

TABLE A1.1 Gray Scale for Color Change Alternate Scales

Discrete Scale	Continuous Scale
5	5
4.5	4–5
4	4
3.5	3–4
3	3
2.5	2–3
2	2
1.5	1–2
1	1

A1.2.1.3 If the computer language used to invoke these equations does not contain a *log2* function, the following relationship will be useful:

$$log_2(X) = \frac{log_{10}(X)}{log_{10}(2)} = \frac{log_n(X)}{log_n(2)} \quad (A1.1)$$

where *n* refers to any base of a logarithm including that of natural logarithms.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE CALCULATIONS FOR GRAY SCALE CHANGE IN COLOR

X1.1 If Table X1.1 is used to check a computer program, discrepancies of ±0.001 or occasionally ±0.002, may arise due to round-off, and do not call into question the program's correctness.

TABLE X1.1 Example Calculations for Gray Scale for Change in Color

Param.	STD-1	BAT-1	STD-2	BAT-2	STD-3	BAT-3	STD-4	BAT-4
X	15.1424	16.5034	27.3479	30.3034	41.4470	46.5670	10.8819	12.7887
Y	18.8150	20.2601	25.5809	31.4791	44.1071	48.6131	11.6227	13.2315
Z	23.0409	24.0848	31.3580	33.0023	49.6602	54.9176	10.8808	15.0329
L*	50.47	52.13	60.41	62.91	72.30	75.21	40.61	43.11
a*	-15.23	-14.49	1.01	1.73	-1.13	1.35	-1.02	1.64
b*	-5.16	-4.08	-0.98	1.05	-2.46	-2.72	4.34	-1.96
C_{ab}	16.08	15.05	1.41	2.02	2.71	3.04	4.46	2.56
h	198.72	195.73	224.14	31.26	245.33	296.40	103.23	309.92
H_M		197.22		307.70		270.86		26.57
x		7.61		0.85		0.09		12.62
ΔL^*_{ab}		1.66		2.50		2.91		2.50
ΔC^*_{ab}		-1.03		0.62		0.33		-1.90
C_M		15.57		1.72		2.87		3.51
D		-0.0001		0.0045		0.0086		0.0000
ΔE^*_{ab}		2.11		3.30		3.83		7.28
ΔH^*_{ab}		0.81		2.06		2.47		6.57
ΔC_K		-1.03		0.61		0.32		-1.90
ΔH_K		0.81		2.06		2.46		6.57
ΔC_F		-1.00		0.61		0.32		-1.90
ΔH_F		0.74		2.06		2.46		6.54
ΔE_F		2.08		3.30		3.85		7.25
G		3.78		3.06		2.83		1.91
GS_C		4.00		3.00		3.00		2.00