Standard Test Method for Measurement of Small Color Differences Between Ceramic Wall or Floor Tile[1]

This standard is issued under the fixed designation C 609; 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 measurement of a visually small color difference between two pieces of solid-colored, glazed or unglazed ceramic tile, using any photoelectric instrument that meets the requirements specified in the test method. The amount and the direction of the color difference are expressed numerically, with sufficient accuracy for use in product specification.

1.2 This test method should not be used for determining small color differences between tile that have a multicolored, speckled, or textured surface, because the results may not be valid.

1.3 Color difference between specimens found to be metamers (see 3.2), by visual examination, can be accurately evaluated by spectrophotometric measurement only. Therefore, visual color comparison of test specimen and reference specimen should be made under incandescent light and under daylight fluorescent light before any instrumental measurement. If visual color difference under the two light sources is not of the same magnitude, the pair of tile must be considered metamers.

1.4 The values stated in inch-pound units are to be regarded as the standard. The values given in parentheses are for information only.

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:*

C 242 Terminology of Ceramic Whitewares and Related Products[2]

D 2244 Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates[3]

E 259 Practice for Preparation of Pressed Powder White Reflectance Factor Transfer Standards for Hemispherical Geometry[3]

E 284 Terminology of Appearance[3]

3. Terminology

3.1 *Definitions:*

3.1.1 *color difference*, ΔE—the vector sum of the three component differences ΔL, Δa, and Δb. It is expressed in units of judds and may be computed by the equation shown under 9.7. The values ΔL, Δa, and Δb are obtained by calculating the component differences as follows:

$$\Delta L = L_t - L_r$$
$$\Delta a = a_t - a_r$$
$$\Delta b = b_t - b_r$$

where:

t = test specimen, and
r = reference specimen.

The quantity ΔE has a positive value and it describes the magnitude but not the direction of color difference between the test specimen and the reference specimen. The direction of color difference depends upon the algebraic signs of the components ΔL, Δa, and Δb. A positive ΔL value means that the test specimen is lighter than the reference against which it is being compared, and a negative ΔL value means that the test specimen is darker. However, the algebraic signs of chromaticity components, Δa and Δb, do not convey an easily visualized difference in color attributes and can best be visualized by plotting the corresponding points in the chromaticity plane.[4]

3.1.2 *color space*—the colors of opaque specimens such as ceramic tile are described in terms of three color scales *L*, *a*, and *b*. Scale *L* is a measure of lightness, *a* is a measure of redness or greenness, and *b* is a measure of yellowness or blueness. The units for each of the three scales are so chosen that they represent equally perceptible color differences. The interrelation of these color scales is more readily visualized if the scales are represented geometrically as the three mutually perpendicular axes of a three-dimensional color space, with the *L* axis in the vertical direction, the positive *a* axis (redness) to

[1] This test method is under the jurisdiction of ASTM Committee C-21 on Ceramic Whitewares and Related Products and is the direct responsibility of Subcommittee C21.06 on Ceramic Tile.

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[2] *Annual Book of ASTM Standards*, Vol 15.02.

[3] *Annual Book of ASTM Standards*, Vol 06.01.

[4] Illing, A. M., Balinkin, I., "Precision in Measurement of Small Color Differences," *American Ceramic Society Bulletin*, Vol 44, No. 12, 1965, pp. 956–962.

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the right, and the positive *b* axis (yellowness) in a counter-clockwise direction from the positive *a* axis (see Fig. 1).

3.1.3 *metamers*—See Terminology E 284.

3.1.4 *reference specimen*—any tile for which a match is desired.

3.1.5 *repeatability*—the standard deviation of results obtained by the same operator using the same instrument in successive measurements.

3.1.6 *reproducibility*—the standard deviation of results obtained by different operators using the same or different types of instruments in different laboratories.

3.1.7 *standard*—the plaque or other media of established tristimulus value, against which standardization of the instrument is made.

3.1.8 *test specimen*—any piece of tile whose color difference from a reference specimen is to be evaluated.

3.1.9 *tile*—See Terminology C 242.

4. Summary of Test Method

4.1 This test method consists of measuring the color of tile specimens with any photoelectric instrument that meets the specified requirements. Such instruments should give results comparable to differences observed by the human eye, and yield for each color a unique, three-number characterization, having known relationship to the tristimulus values *X*, *Y*, and *Z*.

4.2 Some instruments read out directly in the *L*, *a*, and *b* units which are required by this test method. Data from others must be converted to *L*, *a*, and *b* according to the equations given here, or others provided by the instrument supplier. The algebraic differences in *L*, *a*, and *b* values, between any two specimens, are then used to calculate the color difference, ΔE.

4.3 The complete description of the amount and direction of a color difference between any two pieces of tile can be given simply as the three respective differences between the pairs of values for *L*, *a*, and *b*. For some purposes, ΔE alone provides enough information, since its magnitude gives a fairly good correlation with human opinions about the size of a color difference.

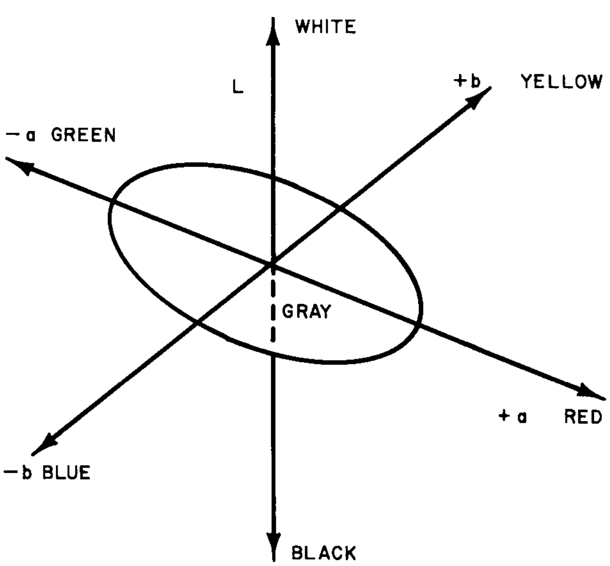

FIG. 1 Three-Dimensional Color Space

4.4 The ΔE units of color difference are usually designated as the National Institute of Standards and Technology (NIST) units of color difference, or simply as "judds."

5. Significance and Use

5.1 The test method described herein provides instrumental means as the basis for judging color difference. Magnitude of color difference between pairs of ceramic tile can be determined and expressed in numerical terms.

5.2 Based on interlaboratory investigation,[4] color difference ΔE of plain-colored tile, if determined according to this test method, should give excellent reproducibility with a standard deviation of not more than $\sigma = \pm 0.15$ judds.

6. Apparatus

6.1 *Type of Instrument*—Any color-measuring instrument either of the spectrophotometer or colorimeter type, capable of yielding data that can be transformed mathematically into the International Commission of Illumination (CIE) tristimulus values *X*, *Y*, and *Z*, may be used. It must have a color difference, ΔE, repeatability (see 3.1.5) of $\sigma = \pm 0.2$ judds or less, based on five independent measurements. The well-known standard deviation equation shown as follows is used to calculate the standard deviation.[5]

$$\sigma = [\Sigma_j F_j (X_j - X)^2 / N]^{1/2} \quad (1)$$

At the present time, spectrophotometers of the Hardy and Cary type and colorimeters such as Gardner and Hunter color difference meters, the Color Eye, Colormaster and Chromosorter, may be considered as suitable instruments.

6.2 *Spectral Characteristics*—The spectral energy distribution of the light source and the spectral sensitivity of the receptor, if necessary, may have to be modified with properly selected filters to provide response functions approximating the tristimulus functions of the CIE standard observer for illuminant C.

7. Standards

7.1 *Primary Standard*—The primary standard for reflectance measurement is a layer of freshly prepared barium sulfate (see Practice E 259).

7.2 *Working Standard*—Because of the difficulty of preparing a primary standard each time and its variability, calibrated pieces of white opaque glass,[6] porcelain enamel plaques, or glazed ceramic tile are used as working standards and are usually supplied by the manufacturer of the instrument. The manufacturer of each type of instrument provides numerical specifications for the working standards, which have a definite relationship to the CIE values *X*, *Y*, and *Z*.

8. Test Specimens

8.1 *Size*—The preferred size of test specimens is 4¼ by 4¼ in. (108 by 108 mm) because most instruments are equipped with a holder of that size which assures that the identical surface area may be measured repeatedly. Specimens larger in

[5] Duncan, A. J., *Quality Control and Industrial Statistics*, R. D. Irwin, Inc., Homewood, IL, 1959, p. 45.

[6] Vitrolite has been found satisfactory for this purpose.

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size may be reduced to that size by cutting. Floor tile are normally produced in sizes smaller than the orifice of most measuring instruments and, therefore, it is necessary to use a mask, which assures that only the color of the specimen is being measured. Such a mask is preferably made of thin metal and should be painted with flat black paint. The opening in the mask should be of such a size as to expose the maximum facial area of the floor-tile specimen without including the edges. Whenever tile are to be measured requiring the use of a mask, it is important that the identical mask be used over the working standard during instrument standardization and on the reference specimen. Only flat portions of the surface of the test specimen or reference may be exposed to the viewing aperture. Tile with insufficient flat area cannot be tested.

8.2 *Selection*—When the test method is to be used for specifications, statistical methods shall be used to determine the number of specimens that will be representative of the lot, but the number shall never be less than five. The required number of specimens shall be randomly selected from the containers which bear identical manufacturer's color and shade designations.

8.3 *Preparation*—The specimen surface that is to be measured for color must be cleaned with a cloth dipped in alcohol, followed by drying with a lintless dry cloth or paper tissue. Unglazed tile, particularly those with absorptions of more than 0.5 % shall be dried in an oven at 200°F (93°C) for a period of 1 h and cooled in a desiccator to room temperature before measurement.

9. Procedure

9.1 *Measurement*—Operate the instrument in accordance with the instructions supplied by the manufacturer, allowing specified warm-up time. Insert the working standard, which comes with the instrument, and set the instrument to the assigned values of the working standard. If a mask must be used for the test specimens, use the same mask on the working standard during standardization. Prepare the test and reference specimens as outlined under 8.3. Take alternate readings of the reference specimen and the test specimen in quick succession until a total of three readings have been made of each tile. Record them and use the average of the three measurements for each tile as the values to be used in calculating color difference. If the number of test specimens to be measured and compared against the same reference exceeds ten, restandardize the instrument against the working standard after each ten test specimens, that is, 60 individual measurements.

10. Calculation

10.1 *Conversion of Readings*—Convert the instrument readings into *L*, *a*, and *b* values in order to calculate color difference. The usual color specification is expressed in terms of CIE tristimulus values *X*, *Y*, and *Z*, in units such that *Y* is the luminous reflectance in percent. Transform these values into *L*, *a* and *b* values as follows (see Test Method D 2244):

$$L = 10Y^{1/2} \tag{2}$$

$$a = 17.5\,(1.02X - Y)/Y^{1/2}$$

$$b = 7.0\,(Y - 0.847Z)/Y^{1/2}$$

The Gardner and Hunter color difference meters read directly in *L*, *a*, and *b* values and do not require any transformation. Spectrophotometers with integrators read the CIE tristimulus values *X*, *Y*, and *Z*, which can be transformed into *L*, *a*, and *b* values in accordance with the equations shown above. Convert readings from the other color-measuring instruments mentioned as suitable under 6.1 into the tristimulus values *X*, *Y*, and *Z*, in accordance with different equations for each type of instrument, as follows:

10.1.1 *Chromosorter*—Convert the data from the chromosorter, given in *x*, *y*, and *R*, as follows:[4]

$$X = (R/y)x \tag{3}$$

$$Y = R \tag{4}$$

$$Z = (R/y)[1 - (x + y)] \tag{5}$$

10.1.2 *Color Eye*—Convert the data from the Color Eye instrument, given in X_{CE}, Y_{CE}, and Z_{CE}, to the CIE tristimulus values *X*, *Y*, and *Z*, as follows:[4]

$$X = 0.6850X_{CE} + 0.1678Z_{CE} \tag{6}$$

$$Y = 0.8764Y_{CE} \tag{7}$$

$$Z = 1.0229Z_{CE} \tag{8}$$

NOTE 1—The Color Eye factors are only typical. Actual factors are the Vitrolite conversion factors as listed on the back of the particular standard supplied with the instrument.

10.1.3 *Colormaster*—Convert the data from the Colormaster instrument, given in *R*, *G*, and *B*, to the CIE tristimulus values *X*, *Y*, and *Z*, as follows (see Test Method D 2244):

$$X = 0.980\,(0.8R + 0.2B) \tag{9}$$

$$Y = G \tag{10}$$

$$Z = 1.181B \tag{11}$$

10.1.4 Obtain the equations to convert the readings from other color-measuring instruments to CIE tristimulus values *X*, *Y*, and *Z*, from the manufacturer of the instrument. The values for *L*, *a*, and *b* can then be calculated by the equations given at the beginning of 10.1.

10.2 *Calculation of Color Difference*— Calculate color difference between each test specimen and the reference against which it is compared from the computed *L*, *a*, and *b* values as follows (see Test Method D 2244):

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2} \tag{12}$$

$$\Delta L = L_t - L_r \tag{13}$$

$$\Delta a = a_t - a_r \tag{14}$$

and

$$\Delta b = b_t - b_r. \tag{15}$$

11. Report

11.1 Report the following information:

11.1.1 Describe the type of test specimen, whether glazed or unglazed, the surface characteristics of glaze (bright, semimat etc.), the common descriptive term of the hue (blue, green, yellow, etc.), and the degree of saturation (strong, medium, weak).

11.1.2 Identify the instrument by manufacturer and model number. Also give type of working standard used, and its calibration.

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11.1.3 Give the equations used for converting the instrument readings to the tristimulus values *X*, *Y*, and *Z*, if different from those specified in this test method, or an instrument different from those mentioned in 6.1 has been used.

11.1.4 Report the color difference, Δ*E*, in judds, between each test specimen and the reference specimen to the nearest tenth of a judd and also give the actual color readings in *L*, *a*, and *b* of the reference and test specimen.

11.1.5 Indicate the direction of color difference for each test specimen by reporting the lightness and chromaticity differences Δ*L*, Δ*a*, and Δ*b*, with their respective algebraic signs.

11.1.6 Use the report form shown in the Annex as a model.

12. Precision and Bias

12.1 The precision of this test method within a single laboratory is determined by the sensitivity of a color-measuring instrument that as specified has a standard deviation of ±0.2 judd when calculating Δ*E* from five independent measurements on the same sample. No interlaboratory data are available.

12.2 *Bias*—No data are available on measurements versus a standard.

13. Keywords

13.1 color differences; color equations; color measurement; glaze color; tristimulus

ANNEX

(Mandatory Information)

A1. COLOR DIFFERENCE REPORT

Type of Specimen

Wall Tile . . . . *Floor Tile* . . . . *Size* . . . . *Glazed* . . . . *Unglazed* . . . .

Glaze Surface: Bright . . . . *Semi-Mat* . . . . *Mat* . . . . *Textured* . . . .

Color Hue: . . . . *Lightness: Dark* . . . . *Medium* . . . . *Light* . . . .

Saturation: Strong . . . . *Medium* . . . . *Weak* . . . .

Type of Instrument

Name: . . . . *Manufacturer:* . . . . *Model No.:* . . . .

Type of Working Standard: . . . . *Calibration of Standard* . . . .

Formulas used to convert instrument readings to CIE values X, Y, and Z.

Results

NOTE—Did visual comparison indicate existence of metamerism? Yes: . . . . No: . . . .

Specimen	Avg of Three Instrument Readings			Readings Converted to CIE Values			CIE Values Transformed to Hunter Color Space Values			Total Color
	a	*a*	*a*	*X*	*Y*	*Z*	*L*	*a*	*b*	
Sample No. 1 Reference										
Directional Color Difference: Δ*L* = Δ*a* = Δ*b* = Δ*E* =										
Sample No. 2 Reference										
Directional Color Difference: Δ*L* = Δ*a* = Δ*b* = Δ*E* =										

[A] Insert here the three notations the particular instrument employs to designate the three measured values. In the case of the Chromosorter, for instance, they would be *x*, *y*, *R*.

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