Designation: C 609 – 07

Standard Test Method for Measurement of Light Reflectance Value and Small Color Differences Between Pieces of Ceramic 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 Light Reflectance Value (LRV) and visually small color difference between pieces of glazed or unglazed ceramic tile, using any spectrophotometer that meets the requirements specified in the test method. LRV and the magnitude and direction of the color difference are expressed numerically, with sufficient accuracy for use in product specification.

1.2 LRV may be measured for either solid-colored tile or tile having a multicolored, speckled, or textured surface. For tile that are not solid-colored, an average reading should be obtained from multiple measurements taken in a pattern representative of the overall sample as described in 9.2 of this test method. Small color difference between tiles should only be measured for solid-color tiles. Small color difference between tile that have a multicolored, speckled, or textured surface, are not valid.

1.3 For solid colored tile, a comparison of the test specimen and reference specimen should be made under incandescent, fluorescent and daylight illuminant conditions. The use of multiple illuminants allows the color difference measurement to be made without the risk of wrongly accepting a match when the tiles being compared are metamers. (See 3.1.4.)

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:* [2]

C 242 Terminology of Ceramic Whitewares and Related Products

D 2244 Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates

E 259 Practice for Preparation of Pressed Powder White Reflectance Factor Transfer Standards for Hemispherical and Bi-Directional Geometries

E 284 Terminology of Appearance

3. Terminology

3.1 *Definitions:*

3.1.1 *color difference,* ΔE^* and ΔE_H—the vector sum of the three component differences ΔL^*, Δa^*, and Δb^* for ΔE^* and $\Delta L_H, \Delta a_H, \Delta b_H$ for ΔE_H. The superscript * indicates color difference based on the use of CIELAB color space equations, while the subscript H indicates color difference based on the use of the Hunter equations. ΔE_H is expressed in units of judds, while ΔE^* is a unit-less value. Either form of the ΔE can be solved for using the equation shown in 10.3. For both the CIELAB and Hunter equations, 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

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

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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.

visualized difference in color attributes and can best be visualized by plotting the corresponding points in the chromaticity plane.[3]

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

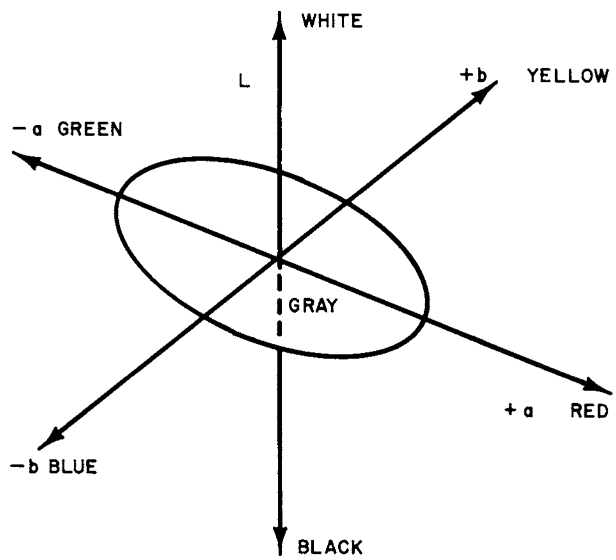

FIG. 1 Three-Dimensional Color Space

3.1.3 *light reflectance value, (LRV)*—the luminance factor *Y*, of a sample expressed as a percent. Thus, a *Y* value of 70 would equate to an LRV of 70%. The LRV indicates the portion of light cast on a sample that is not absorbed.

3.1.4 *metamers*—See Terminology E 284.

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

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

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

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

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

3.1.10 *tile*—See Terminology C 242.

3.1.11 *spectrophotometric*—measurement of the spectral reflectance or transmittance curve of a material.[4].

4. Summary of Test Method

4.1 This test method explains the technique for measuring the LRV and color of tile specimens with a spectrophotometric 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 Spectrophotometic measurement systems commonly provide measurement data in a variety of color units and allow for automatic conversion of data from one color system to another. Select equations are included in this test method for manual determination of LRV from Y, L^* or L_H. Equations are also provided for calculation of L^*,a^* and b^* and L_H, a_H and b_H from tristimulus values X, Y, Z. The algebraic differences in L, a, and b values, between any two specimens, are then used to calculate the color difference, ΔE. If manual calculations are required, consult the instrument supplier for conversions not provided within this test method.

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

4.4 To protect against approval of a metameric color match, multiple illuminates must be used when evaluating color difference between solid colored tiles. A test specimen needs to prove suitable with respect to a reference specimen under incandescent, fluorescent and daylight illuminant conditions in order to be judged as acceptable.

5. Significance and Use

5.1 This test method describes the means of determining the LRV of a tile specimen. Certain building codes require the use of materials rated by LRV. Application of this test method provides the means for rating ceramic tile. LRVs reported for ceramic tile should include reference to the observer and illuminant for which the rating is valid.

5.2 LRV is a property dependent on the overall color of a tile specimen. Control of LRV is achieved through control of color and adherence to color specifications will govern the acceptability of a product with respect to LRV. Therefore, a product cannot be judged as having an unacceptable LRV unless the color of the product is found to be unacceptable.

5.3 Mixtures of several tile products are commonly installed on a surface, requiring a means to calculate LRV for a product mix. The rating obtained for an individual tile product can be used to calculate the LRV for a product mix using the following equation:

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

[4] Billmeyer, F.W. Jr., Saltzman, M., *Principles of Color Technology, 2nd Edition*, John Wiley & Sons, Inc., New York, NY, 1981 p. 78, 85.

$$LRV_{product\ mix} = \Sigma\, p_1 LRV_1 + p_2 LRV_2 + \ldots + p_n\, LRV_n \quad (1)$$

where:

n	=	number of products included in the mix
$p_{1\ to\ n}$	=	the proportion of the surface area taken up by each product, the sum of p_1 to p_n must equal one
LRV_{1} *to n*	=	the LRV for each product used

For example, a mixture of two products is used on a surface. Two thirds of the surface area is covered by product A with a LRV of 75%, and one third of the surface is covered by product B with an LRV of 60% (see Fig. 2). Using the equation, the product mix is found to have an LRV of 70%.

B	A	A	B	A	A	B	A	A
B	A	A	B	A	A	B	A	A
B	A	A	B	A	A	B	A	A
B	A	A	B	A	A	B	A	A
B	A	A	B	A	A	B	A	A
B	A	A	B	A	A	B	A	A

FIG. 2 Example of a Product Mix Used on a Surface

5.4 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.

5.5 Based on interlaboratory investigation,[3] 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 $\sigma = \pm 0.15$ units. LRV should also give excellent reproducibility when used for solid colored tile based on the relationship between LRV and either the Y tristimulus or L value. However, LRV reproducibility for multicolored, speckled, or textured surface tile will be dependent upon the degree of variation of the tile specimen, and will require a different measurement procedure to minimize the impact of the variation.

5.6 The test method requires the use of multiple illuminants for the determination of color difference between solid-colored tiles. Evaluation under incandescent, fluorescent and daylight illuminant conditions ensure the color differences calculated between a test and reference specimen account for the possible occurrence of metamerism.

6. Apparatus

6.1 *Type of Instrument for LRV Measurement*—Any color-measuring spectrophotometric instrument 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 3.1.6) of $\sigma = \pm 0.2$ units or less, based on five independent measurements. The well-known standard deviation equation shown as follows is used to calculate the standard deviation.[5]

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

6.2 *Type of Instrument for Color Measurement*—For the measurement of solid colored tile, the spectrophotometric measurement system must meet all of the requirements for LRV measurement and be capable of yielding tristimulus values X, Y, and Z, for daylight, incandescent and fluorescent illuminants.

6.3 *Instrument Setup*—For measurement of LRV and color difference, spectrophotometric measurements should be taken with specular component included (SCI). If the instrument being used is not capable of taking SCI measurements, then all reported measurements must include a notation stating measurement obtained with specular component excluded (SCE).

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, 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 may be reduced to that size by cutting. The required sample size is dependent on the instrument being used to measure the test and reference specimens. Many instruments can be configured to measure a sample using different size viewing apertures. The largest area of view capable of being used without interference from the edges of the tile should be selected. However, the same aperture size should be used for all measurements involved in a comparison. Tile with surfaces smaller than the aperture opening may not be measured with this test method. Likewise, tile with insufficient flat area cannot be tested for color difference.

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.

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

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 of solid colored tile*—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. 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.

9.2 *Measurement of tile having a multicolored, speckled, or textured surface*—Follow the proscribed procedure for the measurement of solid colored tile with regard to instrument preparation. The number of required sample readings should be determined based upon the surface area of the tile specimen and the area of view of the measurement according to the following formula, rounded to the nearest whole number:

$$Readings\ per\ Sample = \frac{Surface\ Area\ of\ Sample}{(5 * Area\ of\ View\ of\ Measurement)} \quad (3)$$

The measurements should be distributed over the tile in a pattern that will provide representative data for the entire sample. The average of all measurements performed on a tile should be used to represent the LRV of the specimen. As with solid colored tile, no less than five specimens should be used to represent a lot. All measurements for a test specimen should be performed followed by all measurements on a reference specimen, alternating back and forth until the required number of tiles of each type has been measured.

10. Calculation

10.1 *Conversion of Readings*—Convert the instrument readings into *L, a,* and *b* values in order to calculate color difference. Transform CIE tristimulus values X, Y and Z into *L, a* and *b* values as follows (see Test Method D 2244):

$$L^* = 116(Y/Y_n)^{1/3} - 16 \quad (4)$$

$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$

$$b^* = 500[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

$$L_H = 100(Y/Y_n)^{1/2} \quad (5)$$

$$a_H = 175\ [0.0102X_n/(Y/Y_n)]^{1/2} * [(X/X_n) - (Y/Y_n)]$$

$$b_H = 70\ [0.00847Z_n/(Y/Y_n)]^{1/2} * [(Y/Y_n) - (Z/Z_n)]$$

NOTE 1—X_n, Y_n, and Z_n are the tristimulus values for the reference white. The equations for calculating CIEL*a*b* are only valid when X/X_n, Y/Y_n, and Z/Z_n are greater than 0.01.

In order to protect against approval of a metameric color match between the test and reference specimens, L, a, and b values need to be calculated separately for daylight, incandescent and fluorescent illuminant conditions.

10.2 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.

10.3 *Calculation of Color Difference,* Δ*E*— 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):

$$\Delta E = [(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2]^{1/2} \quad (6)$$

$$\Delta L = L_t - L_r \quad (7)$$

$$\Delta a = a_t - a_r \quad (8)$$

and

$$\Delta b = b_t - b_r. \quad (9)$$

In order to protect against approval of a metameric match between the test and reference specimens, color difference needs to be calculated separately using the L, a and b values generated for daylight, incandescent and fluorescent illuminant conditions.

10.4 *Calculation of Light Reflectance Value, LRV*—Calculate LRV value from Y tristimulus, L* or LH as follows:

$$LRV = Y \quad (10)$$

$$LRV = 100((L^* + 16)/116)^3, for\ L^* > 8.000 \quad (11)$$

$$LRV = L^*/9.0329, for\ L^* \leq 8.000$$

$$LRV = 100\ (LH / 100)^2 \quad (12)$$

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, semi-matte 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.

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. List the CIE illuminant designation for the daylight, incandescent and fluorescent illuminants used.

11.1.4 For each of the illuminant conditions (daylight, incandescent and fluorescent), report the LRV or color difference, Δ*E*, between each test specimen and the reference specimen to the nearest tenth of a unit. For Δ*E* give the actual color readings in *L, a,* and *b* of the reference and test specimen.

11.1.5 For each of the illuminant conditions (daylight, incandescent and fluorescent), 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.

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 units when calculating ΔE^* 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; light reflectance; tristimulus