



SURFACE VEHICLE RECOMMENDED PRACTICE

J1545™

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Superseding J1545 OCT2014

(R) Instrumental Color Difference Measurement
for Exterior Finishes, Textiles, and Colored Trim

RATIONALE

SAE J1545 has been reaffirmed to comply with the SAE Five-Year Review policy.

1. Scope

The practice applies to parts and materials used in vehicle manufacture which are intended to be acceptable color matches to a specified color standard. This practice is intended for use with parts or materials that are opaque or nearly so and does not apply to transparent materials. Materials covered by this practice include topcoat paint finishes, interior soft trim, interior and exterior hard trim, and exterior film.

1.1 Purpose

The intent of this practice is to precisely specify procedures for instrumental color difference measurement of colored parts or colored materials incorporated in the manufacture of vehicles. The recommended practice provides a consistent engineering practice for determination of color difference, for numerical communication of color difference, and for determination of acceptance or rejection compared to numerical tolerances. The practice is intended for use as a specification and means of communication for color part acceptance in a buyer-seller agreement.

2. References

2.1 Applicable Publications

NOTE—The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE, ASTM, AATCC, CIE and DIN publications shall apply. CIE publications are available from the USNC-CIE, c/o TLA-Lighting Consultants, Inc., 7 Pond Street, Salem, MA 01970-4819.

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Documents

Document Sharing Hub

- 2.1.1 ASTM E 284—Standard Definitions of Terms Relating to Appearance of Materials available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.
- 2.1.2 Commission International de l'Éclairage, International Lighting Vocabulary, Bureau Central de la CIE, Paris, 1987, 4th ed., Publication CIE No. 17.4 1987.
- 2.1.3 ASTM E 105—Standard Practice Probability Sampling of Materials available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.
- 2.1.4 Commission International de l'Éclairage, Colorimetry, Second Edition, Bureau Central de la CIE, Paris, 1986 – Corrected Reprint 1996, Publication CIE No. 15.2 (1986).
- 2.1.5 Commission International de l'Éclairage, Improvement to Industrial Colour-Difference Evaluation, Publication CIE No. 142 (2001).
- 2.1.6 ASTM D 1729—Standard Practice for the Visual Evaluation of Color Differences of Opaque Materials available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.
- 2.1.7 One source for color performance standards is British Ceramic Research Association Instrument Performance Standards available from Hemmendinger Color Lab, 438 Wendover Drive, Princeton, NJ 08540.
- 2.1.8 One source for external verification is the Color and Appearance Proficiency Testing service available from Collaborative Testing Services, 8343-A Greensboro Dr., McLean, VA 22102.
- 2.1.9 F. J. J. Clarke, R. McDonald, B. Rigg. "Modifications to the JPC 79 Colour-difference Formula", J. Soc. Dyers and Colourists, 100, 128-132 (1984).
- 2.1.10 "Farbtoleranzen für Automobillackierungen, Teil 2: Effektlackierungen" (Tolerances for automotive paints, Part 2: Goniochromatic paints), DIN 6175, Deutsches Institut für Normung e.V., Berlin.
- 2.1.11 AATCC Evaluation Procedure 6, Instrumental Measurement of Textiles, AATCC Technical Manual available from American Association of Textile Chemists and Colorists, P. O. Box 12215, Research Triangle Park, NC 27709.
- 2.1.12 Billmeyer and Saltzman's Principles of Color Technology, 3rd Ed. by Roy S. Berns, Wiley-Interscience, New York, 2000.
- 2.1.13 ASTM D 2244—Standard Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.
- 2.1.14 ASTM E 2194—Standard Practice for Multiangle Color Measurement of Metal Flake Pigmented Materials available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.

2.2 Related Publications

- 2.2.1 ASTM Committee E-12—ASTM Standards on Color and Appearance Measurement, 6th Edition, 2000 available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.
- 2.2.2 ASTM D 3134—Standard Practice for Establishing Color and Gloss Tolerances available from ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959.
- 2.2.3 R. W. Harold, K. Loughrey, T. Mabon, “Benefits of the Sample Averaging Technique,” Hunterlab Application Notes, 4 No. 3, March 21, 1985.
- 2.2.4 Wolfgang Budde, “The Gloss Trap in Diffuse Reflectance Measurements,” Color Research and Application 5, 73-75 (1980).
- 2.2.5 Strocka and Brockes, “Comparison of the CIE (1931) 2° and the CIE (1964) 10° Colorimetric Standard Observer with Individual Observers in the Assessment of Metameric Matches,” Proc. Intern. Color Meeting, Color 69, Stockholm 1969, Vol. 2, pp 785-793.

3. Definitions

NOTE—Except for terms specifically defined in this document, terminology used in this report follows the definitions reported by ASTM (see reference 2.1.1) and the Commission International de l'Éclairage (see reference 2.1.2).

3.1 Product, Lot, Sample, Specimen, Reading, Measurement

3.1.1 PRODUCT

A product is the group of all parts or material having the same color, composition and physical form.

3.1.2 LOT

A lot is the customary unit of production of a product comprising one or more individual product units. For example, a lot of plastic parts might comprise 500 individual product units and a lot of paint material might compromise one 5000 gallon batch of paint.

3.1.3 SAMPLE

A small part or portion of a material or product intended to be representative of the whole from which a specimen is prepared for testing. The sample or group of samples chosen shall be representative of the color difference properties of the product lot (see reference 2.1.3).

3.1.4 SPECIMEN

A piece or portion of a sample used to make a test.

3.1.5 READING

A reading is a single instrumental color difference assessment made in one particular location and in one particular orientation within a specimen. When a multiangle instrument is used to measure a specimen, a reading would refer to a given illuminating and aspecular angle.

3.1.6 MEASUREMENT

A measurement is the estimate of the sample color difference relative to a standard determined from one reading or the mean of multiple readings as specified by the procedure of this recommended practice.

3.1.7 ASPECULAR ANGLE

Viewing angle measured from the specular direction, in the illuminator plane unless otherwise specified.

DISCUSSION—Positive values of the aspecular angle are in the direction toward the illuminator axis.

3.1.8 GONIOAPPEARANCE

The phenomenon in which the appearance of a specimen changes with change in illumination or viewing angle.

DISCUSSION—Examples of gonioappearance are specimens of coatings containing flake pigments.

3.2 Standards

3.2.1 OFFICIAL STANDARD

An official standard is a physical standard that represents the concept color. The official standard physically represents the color target for visual and colorimetric evaluation of all products referenced to that official standard. Where feasible, the official standard should have the same composition and construction as the reference and working standards.

3.2.2 REFERENCE STANDARD

A reference standard is a physical standard used to calibrate working standards. Reference standards shall have the same composition and construction as the working standards and the composition and construction shall be representative of samples of the product. Reference standards are instrumentally referenced to the official standard.

3.2.3 WORKING STANDARD

A working standard is a physical standard in routine use. Working standards are made of material identical to the reference standard and are instrumentally referenced to the official standard.

3.3 Instruments

3.3.1 MASTER INSTRUMENT

The master instrument is an instrument that is used to establish the basic references among various levels of standards and among other instruments. This instrument is the normal arbiter in any situation not adequately resolved at a lower level. This instrument should generally be a spectrophotometer and is usually retained by the organization that issues the standards.

3.3.2 SECONDARY INSTRUMENT

A secondary instrument is any other instrument used for color difference measurement of the product by reference to the standards.

4. *Basic Color Measurements Specifications*

4.1 Standard Observer

The standard observer for colorimetric determination should be the CIE 1964 supplementary standard colorimetric observer (see reference 2.1.4), referred to as the 10° standard observer.

4.2 Standard Illuminant

The standard illuminant for colorimetric determination should be CIE standard illuminant D65 (see reference 2.1.4). If a determination of metamerism is required, CIE standard illuminant A and CIE standard illuminant F2 are recommended.

4.3 Uniform Color Space

The uniform color space for determination of color difference shall be the CIE 1976 ($L^*a^*b^*$) space (see reference 2.1.4). This space may be abbreviated, CIELAB.

4.4 Color Difference

4.4.1 SINGLE ILLUMINATING/VIEWING GEOMETRY MEASUREMENTS

The total color difference between a standard and a specimen shall be expressed using an ellipsoidal equation. ΔE_{cmc} (see references 2.1.9 and 2.1.13) is recommended for this application and CIEDE2000 (see references 2.1.5 and 2.1.13) is an acceptable alternative. Pass/Fail judgments using such a computation are expected to correlate well with visual assessments when care is taken to use multiple observers and the tolerance is sized to fit the acceptable population by using the appropriate weighting factors for the equation being utilized (l : c , cf for the C_{mc} equation; kL , kC , kH for the CIEDE2000 equation). The method outlined on pages 124 and 125 of Reference 2.1.12. can be used as a guide for determining visual tolerances. The ellipsoidal equation must be agreed upon by the supplier and customer.

In addition, color differences between a standard and specimen often need to be described in greater detail than simply in terms of total color difference. In this case, the differences should be quantified in terms of the three components of the metric selected for total color difference. (see Table 1, below.) That is, DE_{cmc} or CIEDE2000 may be used for overall pass/fail assessment, and the corresponding weighted component Lightness, Chroma, and Hue difference terms may be used to describe the specifics of a color difference pair.

For near-neutral colors ($C_{ab}^* < 5$), it is appropriate to use Da^* and Db^* to describe the component color differences in a manner that is consistent with visual assessment (see reference 2.1.10). Refer to Table 1 below for reporting purposes.

TABLE 1—COMPONENTS OF A COLOR-DIFFERENCE EQUATION TO DESCRIBE THE COLOR DIFFERENCE BETWEEN A STANDARD AND A SPECIMEN

Color Difference Equation	Equation Components $C_{ab}^* \geq 5$			Near-Neutral $C_{ab}^* < 5$		
	Lightness	Chrom	Hue	Lightness	Red-Green	Yellow-Blue
CMC(l:c)	$\frac{DL^*}{\ell S_\ell} = DL_{cmc}$	$\frac{DC^*}{c S_C}$	$\frac{DH^*}{S_H}$	$\frac{DL^*}{\ell S_\ell} = DL_{cmc}$	Da*	Db*
CIEDE2000 ($k_L:k_C:k_H$)	$\frac{DL^*}{k_L S_L} = DL_{CIEDE2000}$	$\frac{DC^*}{k_C S_C}$	$\frac{DH^*}{k_H S_H}$	$\frac{DL^*}{k_L S_L} = DL_{CIEDE2000}$	Da*	Db*

NOTE—In Table 1 above, the capital letter D indicates a differential colorimetric value, which is often used in place of the Greek letter Delta, Δ . DL^* , for example would be referred to as Delta L^* .

4.4.1.1 For DE_{cmc} , the weighting of lightness to chroma (l:c) must be agreed upon between supplier and customer and documented.

4.4.1.2 For CIEDE2000, the weighting of lightness to chroma to hue ($k_L:k_C:k_H$) must be agreed upon between supplier and customer and documented.

4.4.2 MULTI-ANGLE MEASUREMENTS

Materials that exhibit different colors depending on the angles of illumination or viewing are called gonioapparent materials. The color difference between a specimen and a standard may vary with the angle of illumination and/or viewing. Color differences between the specimen and standard may be determined as in section 4.4.1 for each illuminating and aspecular geometry.

4.5 Color Difference Tolerance

4.5.1 SINGLE ILLUMINATING/VIEWING GEOMETRY MEASUREMENTS

The total color difference allowed shall be specified as the tolerance for color difference assessment. A specimen is rated acceptable by the color difference assessment if its measured color difference relative to the color standard is within the specified tolerances for the total color difference. A specimen is rated unacceptable by the color difference assessment if its measured color difference relative to the color standard is outside the specified tolerances for the total color difference.

NOTE—Use of the total color difference for pass/fail avoids problems with “corners” of any block-type method (LCH, Lab, etc). This also requires that the standard be in the center of the acceptable volume – no asymmetrical ellipsoids.

4.5.2 MULTI-ANGLE MEASUREMENTS

Tolerances for color differences between the specimen and standard may be specified and evaluated as in section 4.5.1 for each illuminating and aspecular geometry or for a total color difference.

4.5.3 TOLERANCE APPLICATION

When a specimen representing a production batch is of different physical composition than the official standard, e.g., ABS plastic part referenced to the polypropylene official standard, a reference standard of the proper composition should be established. This is because differences in the index of refraction of the two materials may result in significant lack of correlation to visual observation. There is often need for reference standards, even when production batches are of substantially the same composition as official standard, perhaps to measure to a specimen of the same supply source as production source, or perhaps because of the difficulty of precisely reproducing hundreds of exterior color panels.

There will likely be difference in color values between the official and reference standard and between working and reference standard (see section 6.1.2). When using the 3-component color differences described in section 4.4.1, the color tolerances should be adjusted to account for these differences. For example, if the weighted-DL* tolerances were +/- 2 and the reference standard measured +1 weighted-L* unit higher than the official standard, the weighted-DL* tolerances as compared to that reference standard should be adjusted to +1 and -3 units. See figure 1. Similar offsets can be applied to the a and b axes.

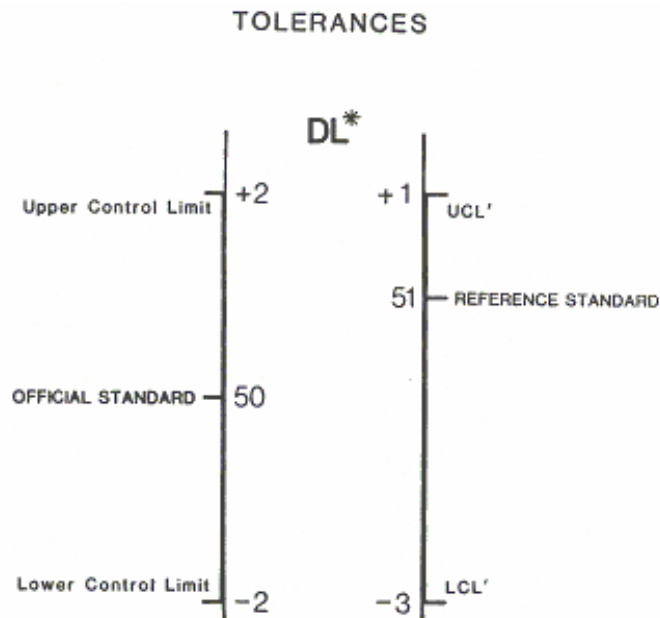


FIGURE 1—EXAMPLE OF THE MODIFICATION OF THE UPPER AND LOWER TOLERANCES OF A REFERENCE STANDARD RELATIVE TO ALLOW FOR THE COLOR DIFFERENCE OF THE REFERENCE

Figure 2 and Table II illustrate this same approach to adjusting ΔE_{CMC} total color difference data from a reference standard. The official standard measures $L^* = 50.00$, $a^* = 8.00$, $b^* = 12.00$. It is shown on an a-b plot as point "O", with a $0.6 \Delta E_{CMC}^*$ tolerance ellipse around it. For simplicity, this is shown as a two dimensional plot, with all data points having $L^* = 50.00$. The reference standard is shown as point "R". It measures $L^* = 50.00$, $a^* = 8.20$, $b^* = 12.20$. Positioned within the tolerance ellipse, it is visually quite acceptable as a match to the official standard. The point marked "OK" plots within the ellipse and has $\Delta E_{CMC} = 0.45$ relative to the official standard and 0.24 relative to the reference standard. The "Test" point plots outside the ellipse yet falls within a $0.6 \Delta E_{CMC}$ ellipse around the reference standard. Because the $\Delta E_{CMC} = 0.55$ versus the reference it would be visually okay. However, it measures $\Delta E_{CMC} = 0.78$ versus the official standard and therefore, would be quite unacceptable. While not having the official standard readily available for the measurement, the offset techniques on the reference standard can still be used. Once the reference standard is approved, it is measured in L, a, b against the official standard. It is important that this measurement be made on the same spectrophotometer, which will be used for acceptability checks. Measurements in this case are $\Delta L^* = 0.00$, $\Delta a^* = 0.20$, $\Delta b^* = 0.20$. The reference standard L^* , a^* , b^* reading is offset by this color difference, and this offset L^* , a^* , b^* is used each time a color difference is calculated.

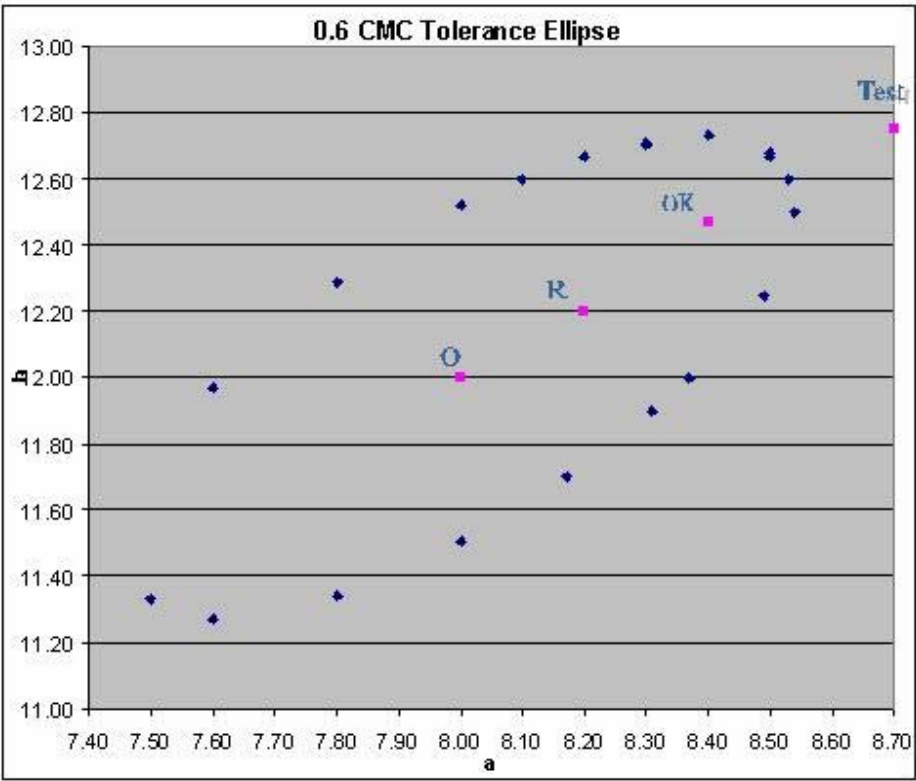


FIGURE 2—0.6 ΔE_{CMC} TOLERANCE ELLIPSE AROUND AN OFFICIAL STANDARD

TABLE 2—OFFSETTING THE REFERENCE STANDARD TO THE OFFICAL STANDARD
AND THE WORKING STANDARD TO THE REFERENCE STANDARD

	L*	a*	b*	ΔL^*	Δa^*	Δb^*	ΔE_{CMC}
Official Standard [O]	50.00	8.00	12.00				
Acceptable datapoint [OK]	50.00	8.40	12.47	0.00	0.40	0.47	0.45
Test datapoint [TEST]	50.00	8.70	12.75	0.00	0.70	0.75	0.78
Reference Standard [R]	50.00	8.20	12.20				
Offset				0.00	-0.20	-0.20	
Offset Reference Standard	50.00	8.00	12.00				
Test vs. Reference				0.00	0.50	0.55	0.55
Test vs. Offset Reference				0.00	0.70	0.75	0.78