



SURFACE VEHICLE RECOMMENDED PRACTICE

J1545

OCT2014

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Superseding J1545 JUL2005

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

RATIONALE

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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- 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 of 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 I, 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 I 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.

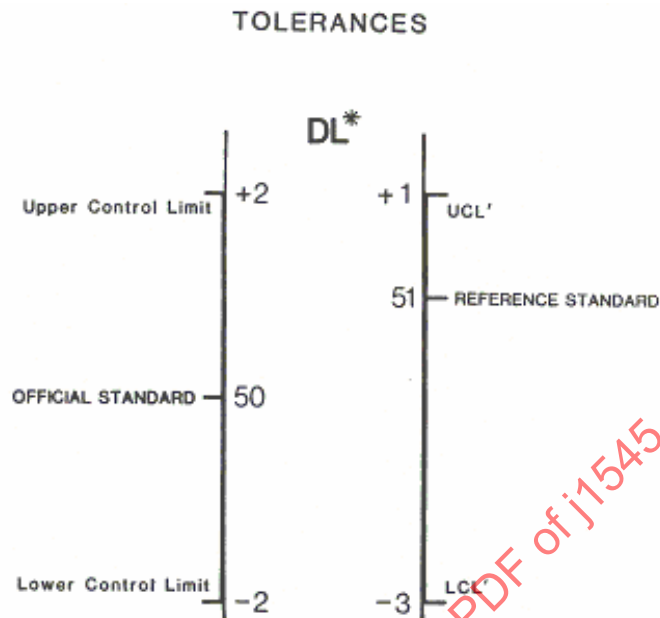


FIGURE 1—EXAMPLE OF THE MODIFICATION OF THE UPPER AND LOWER TOLERANCES OF A REFERENCE STANDARD RELATIVE TO ALLOW FOR THE COLOR DIFFERENCE OF THE REFERENCE

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.

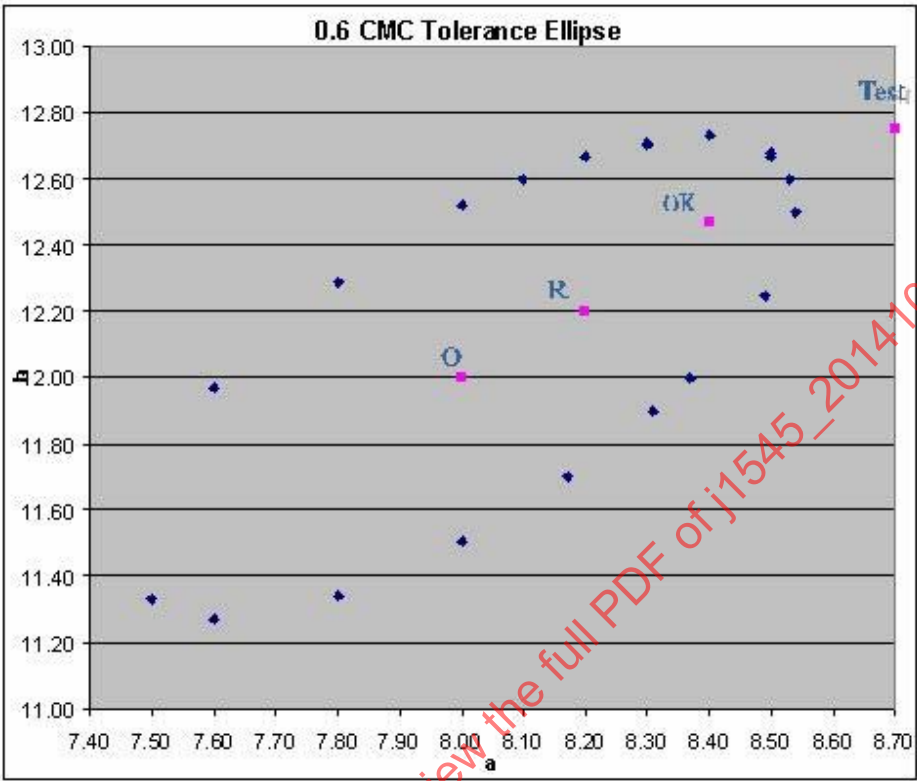


FIGURE 2—0.6 ΔE_{CMC} TOLERANCE ELLIPSE AROUND AN OFFICIAL STANDARD

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

If the reference standard is known to be metameric to the official standard and metamerism is of concern, the offset should be measured under all illuminants of interest. The ΔE_{CMC} calculation is then done for each of these offsets and the calculated values must all fall within the tolerance. The user must also be cautious if working with a pigment mixture allowing for "self metamerism". Another method of calculating the ΔE_{CMC} from the official standard is shown in Appendix B. This method requires knowledge of the K and S values of colorants in the composition.

4.6 Color Measuring Instrument

4.6.1 FOR SINGLE ILLUMINATING/VIEWING GEOMETRY MEASUREMENTS

The instrument used for color difference measurement shall have one of the following illuminating and viewing geometries, unless otherwise specified under Section 7.

- 4.6.1.1 Diffuse/eight-degree geometry, specular component included (di:8°).
- 4.6.1.2 Diffuse/eight-degree geometry, specular component excluded (de:8°).
- 4.6.1.3 Eight degree/diffuse geometry, specular component included (8°:di). This provides equivalent results to 4.6.1.1.
- 4.6.1.4 Eight-degree/diffuse geometry, specular component excluded (8°:de). This provides equivalent results to 4.6.1.2.
- 4.6.1.5 Forty-five degree annular/normal geometry (45°a:0°).
- 4.6.1.6 Normal/forty-five degree annular geometry (0°:45°a). This provides equivalent results to 4.6.1.5.
- 4.6.1.7 Forty-five degree directional/normal geometry (45°x:0°).
- 4.6.1.8 Normal/forty-five degree directional geometry (0°:45°x). This provides equivalent results to 4.6.1.7.

4.6.2 FOR MULTI-ANGLE MEASUREMENTS

4.6.2.1 *The Aspecular Angle*

The aspecular angle is the sensing angle measured from the specular direction, in the illuminator plane as illustrated in Figure 3. The angle is considered positive when measured from the specular direction towards the normal direction. Thus, if a specimen is illuminated at 45° to the normal, the specular reflection will be at -45°. If the receiver is at 65° from the normal and on the same side of the normal as the illuminator, it is receiving reflection from 110° away from the specular direction, which is an aspecular angle of 110°.

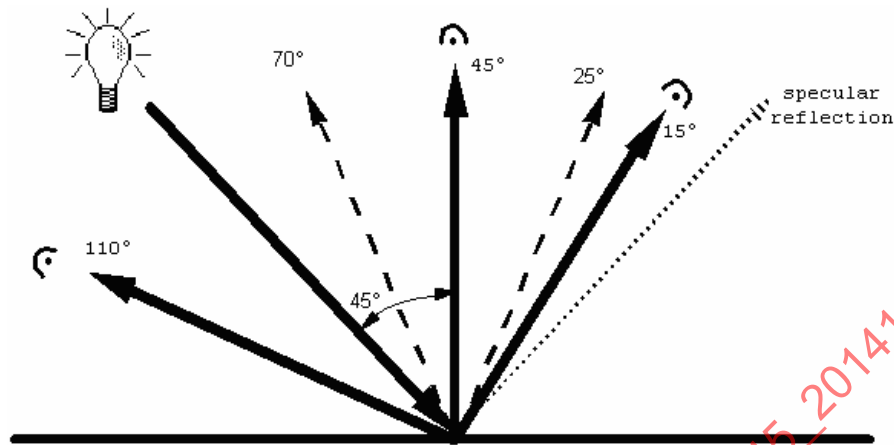


FIGURE 3—THE RECOMMENDED AND ALLOWED ASPECT ANGLES

- 4.6.2.2 Angles for the measurement of materials containing metallic flakes—A minimum of three aspect angles are required to characterize and control these materials—a near aspect angle, a mid aspect angle and a far aspect angle. ASTM E 2194 (see reference 2.1.14) recommends 15° for the near-specular angle (but allows any angle between 15° and 25°), 45° for the mid-aspect angle, and 110° for the far-aspect angle (but allows any angle between 70° and 110°).

NOTE—The illuminator and the receiver can be interchanged for any given geometry.

Some multi-angle color-measuring instruments use annular illumination that illuminates the specimen from a number of azimuthal angles from the specimen's normal. This type of illumination minimizes the contribution from directional effects of the specimen and may produce different answers than an instrument with the illuminator and receiver in the same plane.

- 4.6.2.3 Angles for the measurement of materials containing other effect pigments—Optimized illumination and aspect angles for measuring the reflection from these materials have not been determined. The angles used for measuring materials containing only metallic flake should be used until the optimized angles are determined.
- 4.6.3 Effect of instrument design on color difference measurement—Instruments of differing designs and especially of differing illuminating and viewing geometries do not necessarily result in equivalent color difference values for all specimen differences. The result depends on sample characteristics and instrument design. For this reason, the color difference tolerances for a product may need to have different values with different instrument designs.
- 4.6.4 Effect of appearance on color difference measurement—Appearance characteristics other than color may influence color difference measurement. Examples of these characteristics include gloss, texture, luster, transparency, pile height, and other surface characteristics. For this reason, it is necessary to assure that the specimen and standard have similar appearance characteristics.

4.7 Sample-color Difference Measurement Variability

NOTE—For non-gonioapparent finishes only. Gonioapparent materials are still under evaluation.

The variability of specimen-color difference measurements depends on the variability within the color sample and the variability of the color measurement instrument. In order for the color difference acceptability decision to be valid, the standard errors of the mean estimates of the component color difference scales and/or total color difference must be small fractions of their respective tolerances. Sample color difference acceptability decisions made under this document shall require that the standard error of the mean estimate for each component color difference scale be less than the greater of 0.2 scale units or 0.1 times the tolerance range. The tolerance range is the upper tolerance minus the lower tolerance. See Table A2.

4.7.1 Determination of the standard deviation of specimen color difference measurement—For each product measured under this document, the standard deviations of the specimen color difference measurement must be determined once. The specimen shall be a representative sample of the product. The color difference measurements shall conform to the measurement practices appropriate for the color sample as specified in Section 7. The standard deviations for each component color difference scale and/or the total color difference measurements shall be determined from at least 10 color difference readings of randomly selected areas of the specimen. The standard deviation is calculated with the following equation:

$$S = \sqrt{\frac{\sum (x_i - \bar{x})^2}{N - 1.0}} \quad (\text{Eq. 1})$$

where:

S = the standard deviation

N = number of specimen readings

$\bar{x}$ = is the mean of N specimen readings

x_i = individual specimen reading for the i^{th} reading

4.7.2 STANDARD ERROR OF THE MEAN ESTIMATE

The standard error of the mean estimate (Se) is equal to the standard deviation divided by the square root of the number of specimen readings (N):

$$S_e = \frac{S}{\sqrt{N}} \quad (\text{Eq. 2})$$

where:

N = Number of specimen readings (the sampling number)

S_e = Sampling error

NOTE—The standard error of the mean estimate of a measure of the uncertainty in the estimate of the mean of multiple specimen readings.

4.7.3 STANDARD ERROR OF THE MEAN ESTIMATE WITH A SINGLE MEASUREMENT

If the standard errors of the estimates of all of the component color difference scales and/or the total color difference with one specimen reading do not exceed the greater of 0.2 scale units or 0.1 times their respective tolerance ranges, then a single color difference measurement is valid under this practice. In this case, $N=1$, and the standard error of the estimate is equal to the standard deviation.

$$S_e = S \text{ if } N = 1 \quad (\text{Eq. 3})$$

NOTE—This equation applies only to non-gonioapparent materials.

NOTE—Samples taken from future lots of the same product and measured with the same instrument and procedures shall require one specimen of reading.

4.7.4 STANDARD ERROR OF THE MEAN ESTIMATE WITH MULTIPLE MEASUREMENTS

If the standard errors of the mean estimates with a single measurement exceed the greater of 0.2 scale units or 0.1 times the tolerance range, then multiple measurements are required. Averaging multiple measurements in varying areas of the specimen can reduce the standard error of the mean to acceptable levels. The sampling number, N , required to meet the standard error of the mean estimate criterion is determined by rearranging Equation 2:

$$N = \left(\frac{S}{S_{e,g}} \right)^2 \quad (\text{Eq. 4})$$

NOTE—For each component color difference scale and/or the total color difference determine the sampling number by substituting the specimen-color difference measurement standard deviation (S) and the standard error of the mean estimate goal ($S_{e,g}$) into Equation 4. The standard error of the estimate goal is the greater of 0.2 scale units or 0.1 times the tolerance range. Round each sampling number to the next larger integer value. The product sampling number shall be the largest of the sampling numbers. Samples taken from future lots of the same product and measured with the same instrument and procedures shall require that all specimen color difference measurements be the mean of N readings in varying specimen areas.

4.7.5 ADDITIONAL INFORMATION

Appendix A, provides additional information on specimen color difference measurement variability including the rationale for this procedure and an example calculation.

4.8 Report

The user shall:

4.8.1 Identify the standard.

4.8.2 Identify the specimen.

- 4.8.3 Report the standard observer.
- 4.8.4 Report the standard illuminant.
- 4.8.5 Report the sampling number.
- 4.8.6 Report the standard error of the mean estimate.
- 4.8.7 Report the values of the constants used in the color-difference equation.
- 4.8.8 Report the measurement geometry or geometries.
- 4.8.9 Report the color values at each geometry.
- 4.8.10 Report the color-difference values from the standard at each geometry.

5. Tolerance Determination

5.1 General Tolerance Concepts

A tolerance is the permissible variation of an object in some characteristic. Tolerances are agreed upon between buyer and seller and could be part of the purchasing contract. In reference to this document, color tolerances of automotive materials are separately expressed in terms of the three perceptual variables; hue, chroma, and lightness. (See 4.5.) The reference material is the agreed-upon standard material. Tolerances are normally the sum of the variability in the material manufacturing process and the method used to assess the tolerance. For colored materials, especially materials that need to match or harmonize, the overriding factor for tolerances is the degree of mismatch that can be visually tolerated in the application. Tolerances are, therefore, usually set by visual methods.

5.2 Procedures for Visual Determination of Tolerances

Visual tolerances shall be set up by preparing and judging color specimens differing in defined ways. Since tolerances are expressed relatively in terms of differences and are likely to change only slowly across color space, tolerance experience developed for one color may be applied to other colored materials of similar construction having similar hue, chroma, and lightness. The viewing situation has an important influence on color tolerances. Therefore, the viewing conditions should simulate the end use application. Appearance and width of the line separating the two color fields to be compared shall be similar to the appearance and width of the line separating the colored fields in the final application. Color specimens should be selected which exhibit increasing visual distances from the standard in the hue, chroma, and lightness variables. The differences represented by pairs of standard and specimen are visually assessed by a panel of observers. The visual conditions of assessment shall generally conform to ASTM D 1729 (see reference 2.1.6). Tolerances shall be set based on the visual judgments and the measured and calculated hue, chroma, lightness differences between pairs of specimens.

NOTE—See pages 124-125 in *Billmeyer and Saltzman's Principles of Color Technology*, 3^d Edition.

6. Standards and Instruments

6.1 Standards Procedures

Standards are used for colorimetric control of the product and to maintain the validity of the test procedure.

6.1.1 STANDARDS

The composition and construction of reference standards, working standards, and the product to be colorimetrically controlled with these standards shall be identical. Normally, the official standard will also have identical composition and construction to the reference standards, working standards and product. In those cases where an official standard in the material of the product *does not exist*, it is permissible to calibrate the reference standard to an official standard of the same color in another similar product form. For example, an ABS molded part reference standard could be calibrated to a polypropylene molded part official standard. See Figure 4.

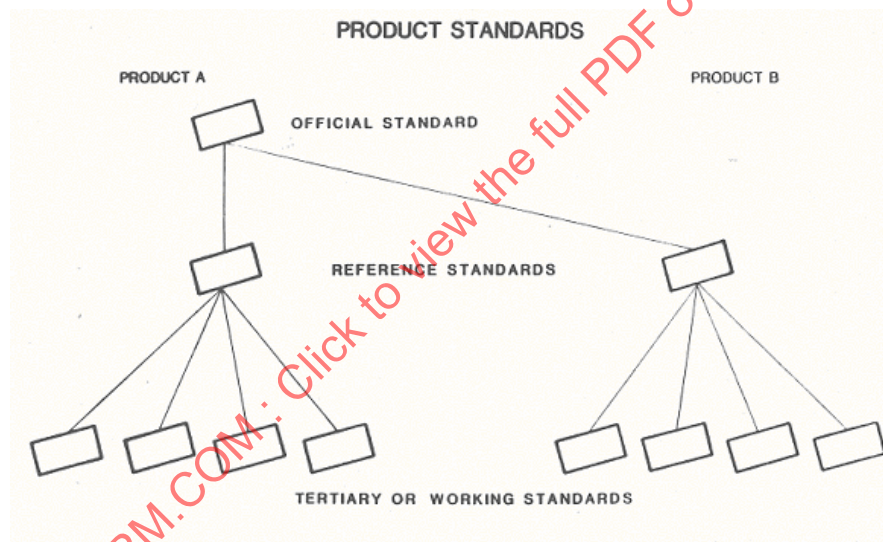


FIGURE 4—NETWORK SHOWING THE RELATIONSHIPS BETWEEN OFFICIAL, REFERENCE, AND WORKING STANDARDS

For product a, the official reference and working standards have the same composition and construction as the product. An official standard was not prepared for product b. In this case, the reference and working standards have the same composition and construction as the product.

6.1.2 STANDARDIZATION PROCEDURE

A quantity of reference standards is prepared and instrumentally referenced to the official standard (see section 4.5.1). At this point, the official standard should be labeled, dated, and placed in storage. Proper storage requires that the standards be stored so as to preserve their color by minimizing the influence of factors such as light, temperature, and contamination. Both the customer and the supplier should retain a quantity of reference standards. These, also, should be labeled, dated, and placed in storage. One of these reference standards at a time should be designated as the current reference standard and this standard should be used until it is deemed unreliable for this purpose. At such time, it should be discarded and a fresh reference standard employed. Unreliability would generally be determined by reference to other reserved reference standards or, ultimately, to the official standard. Similarly, a quantity of working standards is prepared and instrumentally referenced to the current reference standard. One of these working standards is designated the current working standard and the remainder are labeled, dated, and placed in storage. Working standards are used routinely by the instrument operator to compare specimens of the product to the established standard. It is from a working standard that the color tolerances are applied to judge the acceptability or unacceptability of a sample. When a working standard is judged unreliable, by reference to the current reference standard, it should be discarded and a fresh working standard substituted. The reliability of reference standards and working standards should be evaluated on a scheduled basis. If the current measurement of the standard varies from its assigned values by more than the greater of 0.2 scale units or 0.1 times the tolerance range, then the standard should be discarded.

6.2 Instrument Procedures

One instrument is designated as the master instrument. Its primary purpose is to provide the instrumental reference between the official standard and any reference standard. An additional purpose is to serve as a "referee" instrument in the event of any dispute or question concerning any lower level standard or any secondary instrument. Measurements from the master instrument shall be used to calculate color values using illuminant D65 and the 10 degrees standard observer when metamerism may be present between the official standard and the reference standard. Secondary instruments are used for routine measurement and control of finished product. They also serve to determine the relationship between reference and working standards as well as to determine the reliability of a particular reference or working standard. The network of instruments and standards is illustrated in Figure 5.

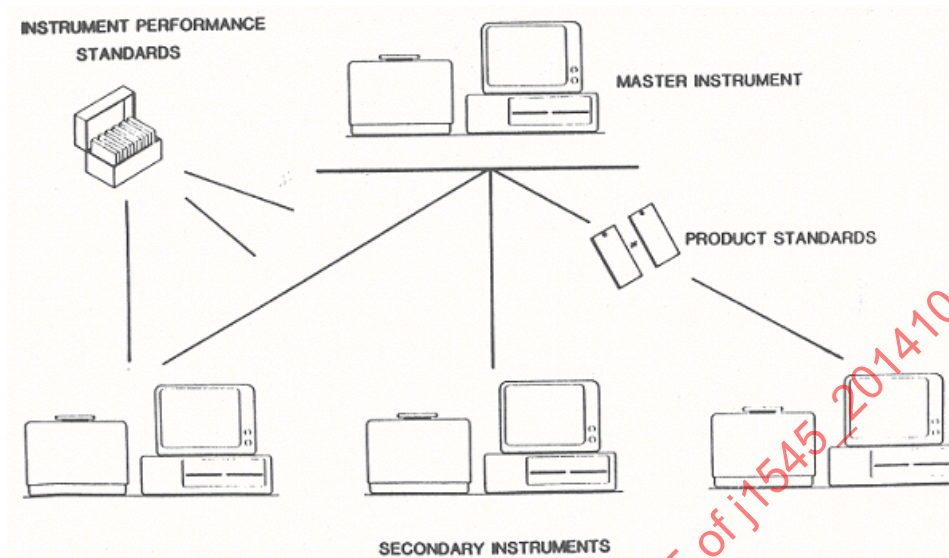


FIGURE 5—NETWORK SHOWING THE RELATIONSHIPS BETWEEN MASTER AND SECONDARY INSTRUMENTS AND INSTRUMENT PERFORMANCE AND PRODUCT STANDARDS

6.3 System Maintenance

A color control program is a complex scheme involving product, instruments, standards, procedures, and personnel. Any measurement is only an approximation of the exactly current state of the material and the instrument being used. Care should be used in both the setup of the program and the necessary maintenance of the program to insure consistent and reliable results. Proper attention to certain areas, including the use of unbiased external resources, should be considered to insure the integrity of any color control program. The intent of this section is to recommend certain practices that should *ensure* this integrity.

6.3.1 INSTRUMENT VERIFICATION PROCEDURE

Instrument performance standards that are independent of the product standards should be used to periodically verify the performance of master and secondary instruments. Instrument performance standards are available from the instrument manufacturer or from an independent source (see reference 2.1.7).

6.3.2 EXTERNAL VERIFICATION SERVICE

Outside resources are useful in the verification process (see reference 2.1.8). They provide an unbiased reference as to the performance of both the instruments and personnel involved in the program.

7. Measurement Practices

7.1 Exterior Finishes and Other High Gloss Applications

7.1.1 SCOPE

The practice described in this section refers to high-gloss exterior paints and decorative films.

7.1.2 INSTRUMENT

The instrument used for these measurements shall conform to one of the sets of illuminating and viewing geometries specified in section 4.6. When a single illuminating/viewing geometry is used to measure finishes containing oriented flake type pigments, it is possible that the specimen and standard will not match for other measurement geometries. Visually, the observed effect is that the specimen may match the standard at some viewing angle and not match the standard at others. For these applications, multiple geometry measurements will provide better control of geometric differences. See B.1.3.

7.1.3 SPECIMEN PREPARATION

Specimens of exterior finishes should be prepared using appropriate substrate, primer and film thickness as specified for the end use of the product. For other than production parts, specimen size should be at least 3 x 5 in (75 x 125 mm). Specimens must be clean and free from scratches and other defects in the area to be measured. The specimen should be similar to the standard in gloss and texture.

7.1.4 SPECIMEN PRESENTATION

Specimen and standard should be oriented in the same direction. When making multiple measurements, care must be taken to avoid the edges of the panel because of the tendency for excessive film build in these areas. The number of measurements required shall be determined as described in section 4.7.

7.2 Textiles

7.2.1 SCOPE

The practice described in this section refers to colored fibrous materials. These products include but are not limited to body cloth, headlining cloth, carpet, webbing, straps, and flocking.

7.2.2 INSTRUMENT

The instrument used for these measurements shall conform to one of the sets of illuminating and viewing geometries specified in section 4.6.

7.2.3 SPECIMEN PREPARATION

Textile specimens must be prepared before presentation to an instrument. Specimens must be clean and free from lint, creases, and other distortions. A lint roller or brush should be used to clean the specimens. Pile fabrics and carpet must be oriented in the natural direction of pile lay. Once the direction is identified, a lint roller or brush should be used to orient the pile. Textile specimens and standards should be similar in luster, texture, and physical form. For additional information, specific to textiles (see reference 2.1.11). For multicolored pattern textiles, the individual components of the pattern should be visually similar to those of the standard. Figure 6 shows two specimens that are visually different but numerically the same. Color difference readings between these two specimens would be meaningless.

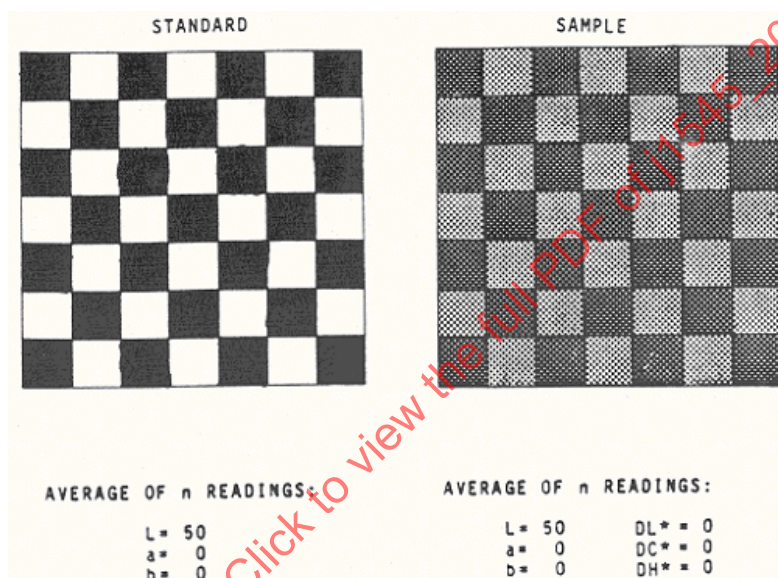


FIGURE 6—HYPOTHETICAL EXAMPLE OF A MULTICOLOR SPECIMEN AND STANDARD

While the mean color difference scale readings are within tolerance, the specimen is unacceptable because the individual components of the pattern do not visually match the individual components of the standard pattern.

NOTE—The size of textile specimens should be approximately 200 x 250 mm (8 x 10 in). If this is not possible, as may be the case for webbing and straps, a 250 mm (10 in) length of the standard width should be used.

7.2.4 SPECIMEN PRESENTATION

Multiple readings are required to account for variation in color and to minimize the influence of directionality. Accordingly, the determinations of standard deviation (see section 4.7.1) and sampling number (see section 4.7.4) are modified for textile specimens. The standard deviation is determined from 12 specimen readings with each reading in a different position and with the 12 readings evenly apportioned to specimen orientations of 0° , 90° , 180° , and 270° in relation to an arbitrarily selected reference direction on the specimen. In order to minimize the influence of directionality for all illuminating/viewing geometries, equal numbers of each of the four directional orientations must be used. Therefore, the allowed sampling numbers for textiles are 4, 8, 12, 16, etc. The textile sampling number shall be the sampling number (see section 4.7.4) raised to the next larger multiple of four. The textile specimen measurement shall comprise the specified number of readings in N different positions with N/4 of the readings in each of the four orientations. Figure 7 illustrates the positions and orientations of the readings for a textile specimen with a sampling number of four.



FIGURE 7—FOR TEXTILE SPECIMEN MEASUREMENT, A MINIMUM MEASUREMENT IS THE MEAN OF FOUR READINGS WITH EACH READING TAKEN WITH A DIFFERENT SPECIMEN AREA AND SPECIMEN ORIENTATION AS ILLUSTRATED

If the specimen is not fully opaque, several layers of material may be required to obtain a valid measurement. To determine whether an additional layer is necessary, two readings, one with a white substrate, and one with a neutral black substrate with reflectance values less than 5% shall be taken. If the DL^* , DC^* , and DH^* values of the two readings are all less than the greater of 0.2 scale units or 0.1 times each tolerance range, an additional layer of material will not be required. The backing for all textile color measurements shall be a neutral black with reflectance values less than 5%. The measurement shall be made at the plane of the specimen port. See reference 2.1.11 for additional information specific to textiles. The use of glass at the aperture shall be permitted for pile specimens if the subsequent measurements are mathematically corrected for the presence of the glass (see reference 2.1.11) and if the specimens are compressed behind the glass to provide consistent measurements. Users may find that the number of readings required for averaging to comprise a single measurement is fewer with proper use of glass than without.

7.3 Colored Trim

7.3.1 SCOPE

The practice described in this section refers to materials that are pigmented and generally have low gloss. These include painted low-gloss and semi-gloss parts, leather, coated fabrics, unsupported low gloss film, and color-impregnated plastics.

7.3.2 INSTRUMENT

The instrument used for these measurements shall conform to one of the sets of illuminating and viewing geometries specified in section 4.6.

7.3.3 SPECIMEN PREPARATION

Specimens must be clean and free from scratches and other distortions. Specimens should be similar to the standard in gloss and surface texture. When measuring multicolor patterned materials and parts, the individual color components should be similar in pattern and general color. Multicolor parts must not be compared in measurement to solid color parts.

7.3.4 SPECIMEN PRESENTATION

For materials of a directional nature, specimen and standard should be oriented in the same direction. Materials and parts described in this section are presumed to be essentially opaque. If some light transmission is likely, use a neutral black sample backing with reflectance values less than 5%. Sampling of solid color parts and multicolor parts shall conform to the guidelines in section 4.7.

8. Notes

8.1 Marginal Indicia

The change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. An (R) symbol to the left of the document title indicates a complete revision of the report.

PREPARED BY THE SAE TEXTILES AND FLEXIBLE PLASTICS COMMITTEE

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