Designation: D 6441 – 99a$^{\epsilon 1}$

Standard Test Methods for Measuring the Hiding Power of Powder Coatings[1]

This standard is issued under the fixed designation D 6441; 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.

ε[1] NOTE—Last line of Table 1 editorially corrected in February 2000.

1. Scope

1.1 These test methods determine and report the hiding power of a powder coating with respect to two parameters:

1.1.1 Test Method A—Contrast Ratio at a given film thickness

1.1.2 Test Method B—Film thickness at 0.98 (98 %) contrast ratio.

NOTE 1—The measured parameters conform to powder coating industry practice by measuring hiding power in relation to film thickness, rather than the more conventional "Spreading Rate" function employed in Test Methods D 344 and D 2805 and other hiding power test methods.

NOTE 2—Hiding power is photometrically defined as the spreading rate at 0.98 contrast ratio. See definitions of spreading rate and hiding power in Terminology D 16, D 2805, and the *Paint and Coatings Testing Manual*.

NOTE 3—The contrast ratio 0.98 is conventionally accepted in the coatings industry as representing "complete" hiding for reflectometric hiding power measurements. But visually, as well as photometrically, it is slightly less than complete.

1.2 These test methods cover the determination of the hiding power of powder coatings applied by electrostatic spraying.

1.3 These test methods determine hiding power by means of reflectometric and thickness gage measurements. They are limited to coatings having a minimum CIE-Y reflectance of 15 %.

1.4 The values stated in SI 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 to determine in advance the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 16 Terminology for Paint, and Related Coatings, Materials, and Applications[2]

D 344 Test Method for Relative Hiding Power of Paints by the Visual Evaluation of Brushouts[2]

D 2805 Test Method for Hiding Power of Paints by Reflectometry[2]

D 3451 Practices for Testing Polymeric Powders and Powder Coatings[3]

E 284 Terminology Relating to Appearance[2]

E 1331 Test Method for Reflectance Factor and Color by Spectrophotometry Using Hemispherical Geometry[2]

E 1347 Test Method for Color and Color Difference Measurement by Tristimulus (Filter) Colorimetry[2]

E 1349 Test Method for Reflectance Factor and Color by Spectophotometry Using Bidirectional Geometry[2]

2.2 *Other Standard:*

1-GP-71, Method 14.7, Hiding Power, Contrast Ratio Method, October 1982[4]

2.3 Paint & Coatings Testing Manual (Gardner-Sward Handbook), 14th Edition, Chapter 42, Hiding Power[5]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *reflectance*—term of wide applicability, referring herein to the *luminous reflectance factor* as defined in Terminology E 284, and equivalent to the CIE Tristimulus value *Y* measured in accordance with Test Methods E 1331, E 1347 or Test Method E 1349 with specular reflection excluded. It is expressed as a percentage in this standard.

3.1.2 *white substrate*—*For purposes of this test,* a substrate of neutral shade with a minimum reflectance of 78 %.

3.1.3 *black substrate*—A substrate with a maximum reflectance of 1 %, which is effectively zero for the purpose of measuring hiding power.

3.1.4 *white reflectance* (R_W)—Reflectance of the applied test film over a white substrate of reflectance *W*.

[1] These test methods are under the jurisdiction of ASTM Committee D-1 on Paint and Related Coatings, Materials, and Applications and the direct responsibility of Subcommittee D01.51 on Powder Coatings.

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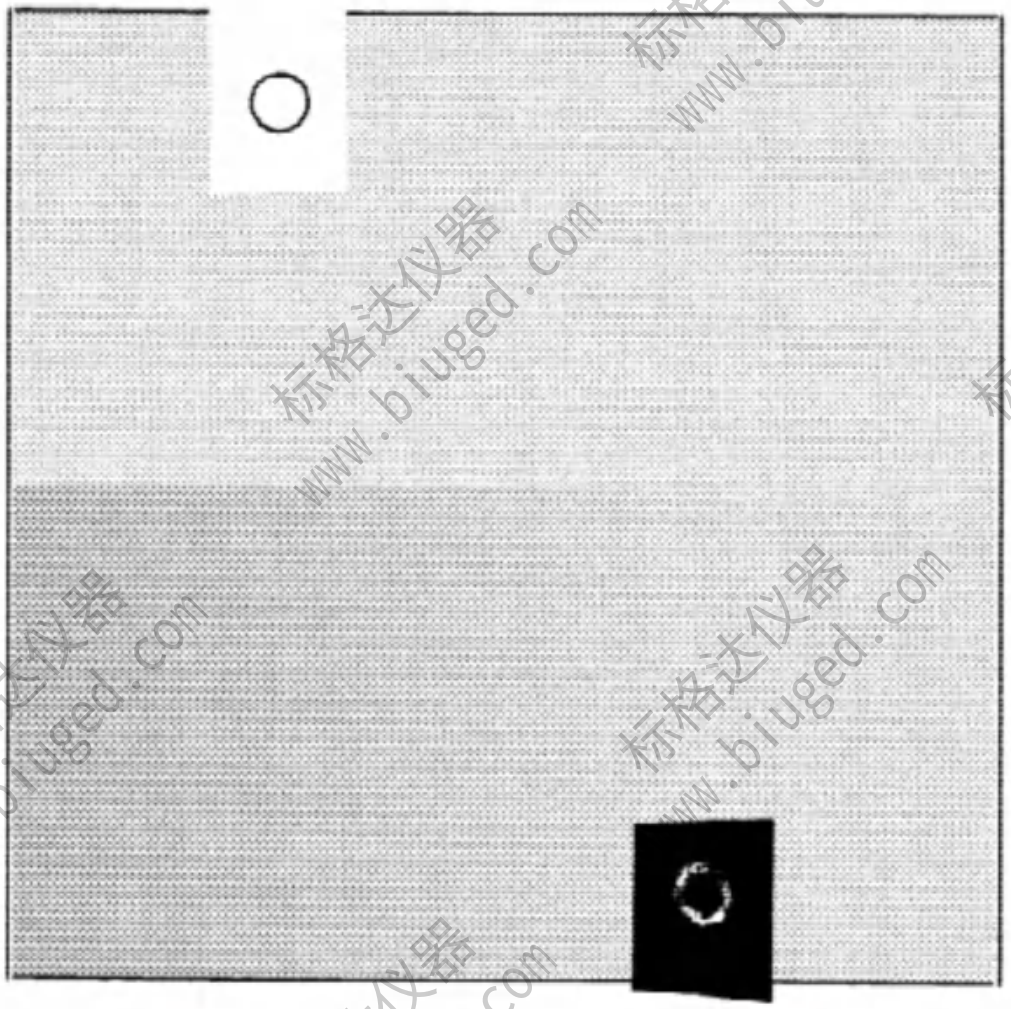
[2] *Annual Book of ASTM Standards*, Vol 06.01.

[3] *Annual Book of ASTM Standards*, Vol 06.02.

[4] Canadian General Standards Board, (CGSB), 222 Queen St., Ottawa, Ont., Canada K1A 1G6.

[5] *Paint & Coatings Testing Manual*, MNL 17, ASTM, 1995.



NOTE 1—Shows black and white substrate areas exposed after removal of masking tape.

FIG. 1 "Wedge" Film Application

3.1.5 *black reflectance* (R_o)—Reflectance of the applied test film over a black substrate.

3.1.6 *reflectivity* (R_∞)—The reflectance of a coating applied thickly enough to be completely opaque, as evidenced by equal reflectance over the black and a white test substrate.

3.1.7 *contrast ratio* (C_W)—(*1*) The ratio of the reflectance of a film applied on a black substrate to a film of equal thickness applied on a white substrate. (*2*) An instrumental measure of film opacity.

3.1.7.1 *Discussion*—Contrast ratio can be expressed as a decimal fraction (R_O/R_W) or as a percentage ($100R_O/R_W$), the latter being preferred for the general concept of hiding or opacity, and employed in these test methods.

3.1.8 *opacity*—The degree to which a coating film hides a black and white substrate, as perceived visually or as measured instrumentally, (see *contrast ratio* defined in 3.1.7).

3.1.9 *wedge of coating*—A film of coating having a range of film thickness giving a corresponding range of opacities on a black and white substrate. (see Fig. 1).

3.2 *Symbols:*

3.2.1 T—the specified or measured thickness of the test coating on the substrate.

3.2.2 t_o—the amount by which the black substrate exceeds the white substrate in thickness.

3.2.3 T'—$T + t_o$; the thickness reading corresponding to T over the black substrate when measured with the gage calibrated to the white substrate as zero.

3.3 For additional definitions applicable to these test methods see Terminology E 284.

4. Summary of Test Method

4.1 *Test Method A—Contrast Ratio (C_W) at a Specified Film Thickness*:

4.1.1 The coating is applied as a "wedge" on a specified test panel.

4.1.2 Several pairs of points are encircled over the black and white substrate at the specified coating thickness, their reflectances R_O and R_W are measured, and their contrast ratios ($C_W = 100\ R_O/R_W$) calculated.

4.1.3 The mean contrast ratio for the panel is calculated.

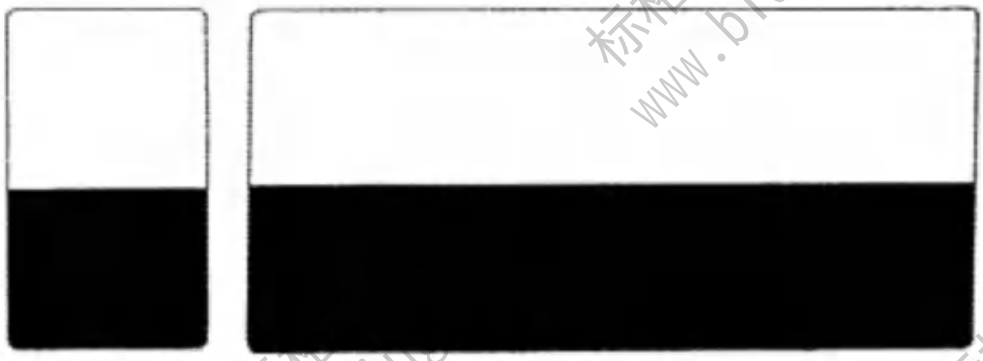


FIG. 2 Examples of Commercially Available Test Panels

4.2 *Test Method B—Film Thickness (T_{98}) at a Contrast Ratio of 98 %*:

4.2.1 The coating is applied as a "wedge" on the specified test panel.

4.2.2 Several equal thickness pairs of black and white substrate points, at varying thicknesses, are located and their contrast ratios determined.

4.2.3 Contrast ratio versus film thickness is plotted on suitable graph paper, and the thickness at T_{98} determined from the graph.

5. Significance and Use

5.1 Contrast ratio at a specified film thickness is a useful hiding power parameter for production control and purchasing specifications.

5.2 The greater the hiding power, the less coating is required per unit area to obtain adequate hiding. Knowledge of hiding power is therefore important in regard to coating costs and for comparing coating value.

6. Apparatus and Material

6.1 *Reflectometer*, that measures the luminous reflectance factor, (specular reflection excluded) using CIE standard illuminant C and the CIE 1931 (2°) standard observer, in accordance with Test Method E 1331, E 1347 or E 1349. The instrument shall be capable of viewing a diameter of at least 3 to 5 mm (⅛ to 3⁄16in.).

NOTE 4—Other observer-illuminant combinations and apertures may be used by agreement.

6.2 *Test Panels:* Smooth, glossy, painted steel panels, thickness approximately 0.28 mm (0.011 in.), divided equally into black and white areas by a straight boundary. The black area shall have a maximum reflectance of 1 % and the white area a minimum reflectance of 78 %. The white area shall not yellow or darken appreciably when subjected to a normal powder coating baking schedule.[6] (see Fig. 2 for commercially available sizes.)

NOTE 5—Some test panels require a pre-bake before using, to expell residual volatiles that can create pinholes in the subsequently applied powder coating. When necessary pre-bake for 10 min at 180°C (350°F) to eliminate this problem.

6.3 Suitable equipment for applying and baking the test coatings.

6.4 *Electronic Gage*, adequately sensitive for measuring coating film thickness.

6.5 *Heat-Resistant Tape*, 20-mm (¾-in.) wide, easily removed after baking, leaving no discoloration or adhesive residue.[7]

6.6 *Permanent Marker*, extra fine point.

6.7 *Suitable Graph Paper.*

7. Measurements—General Rules

7.1 For each powder and test method, fill out an individual work sheet in the form of a table (see Fig. 3 for Test Method A, Fig. 4 for Test Method B), into which all test data and calculated values are entered in the indicated locations.

7.2 Measure reflectance as a percentage to two decimal places. Calculate (or measure) contrast ratio (C_W) as a percentage ($100R_B/R_W$) to two decimal places, and report final results to one decimal place.

7.3 The circles drawn to locate measurement points must be at least larger than the measurement opening of the reflectometer.

7.4 Measure thickness as accurately as possible, reporting to nearest 1.3 µm (0.05 mils), or closer if possible.

8. Calibration and Panel Preparation

8.1 Select a panel and pre-bake if necessary, as discussed in Note 5.

8.2 Locate and encircle a point of mean thickness in the white and in the black areas about 20-mm (¾ in.) from the panel edge, and mask each point with a short length of the specified tape, extending over the edge.

[6] The sole source of supply of panels known to the committee at this time is the Leneta Company, 15 Whitney Rd., Mahwah, NJ 07430. If you are aware of alternative suppliers, please provide this Information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

[7] The sole source of supply of the tape, Product No. 8902 known to the committee at this time is 3M industrial Tape Division; 3M Center 220-8E-04; St. Paul, MN 55144. If you are aware of alternative suppliers, please provide this Information to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,[1] which you may attend.

% Contrast Ratio at a Specified Film Thickness (T)

($T' = T + t_0$)

Coating ID: _____ Circle: mils µm

Color Description: _____ Reflectivity R_∞ _____ %

Gloss Description: _____ Laboratory: _____

T=	Panel 1	t_0 = T' =		Panel 2	t_0 = T' =		Panel 3	t_0 = T' =		Panel 4	t_0 = T' =	
Pair No.	R_O	R_W	C_W	R_O	R_W	C_W	R_O	R_W	C_W	R_O	R_W	C_W
1												
2												
3												
4												
5												
Mean												

Operator: _____ Date: _____ Overall Mean % C_W: _____

T=	Panel 1	t_0 = T' =		Panel 2	t_0 = T' =		Panel 3	t_0 = T' =		Panel 4	t_0 = T' =	
Pair No.	R_O	R_W	C_W	R_O	R_W	C_W	R_O	R_W	C_W	R_O	R_W	C_W
1												
2												
3												
4												
5												
Mean												

Operator: _____ Date: _____ Overall Mean % C_W: _____

FIG. 3 Work Table for Test Method A

8.3 With the panel thus prepared, apply the test coating as a thickness "wedge", cure at the specified schedule, then remove the tapes to expose the uncoated white and black substrate points (see Fig. 1).

8.4 Recalibrate the film thickness gage to zero on the white-substrate points, then measure the thickness of the black substrate point and record as t_0 in the indicated location of the relevant work sheet in the form of a table (see 7.1).

NOTE 6—The black substrate is always thicker than the white by an amount t_0 that is determined for each panel.

NOTE 7—With thickness gages capable of dual calibration, calibrate also to zero on the black substrate point and store both the white and black calibrations.

8.5 Measure the coating reflectance of one panel for each test coating, at a location of visually complete opacity. Record this value as the reflectivity R_∞ of the coating, in the indicated location of the work table.

9. Procedure and Calculations—Test Method A, Percent Contrast Ratio (C_W) at a Given Film Thickness

9.1 Use Fig. 3 for entries in this test method.

9.2 Record the thickness (T) for which the contrast ratio is to be determined.

NOTE 8—For significance and adequate sensitivity, the thickness should be such that the mean contrast ratio is not much over 98 % and preferably less.

9.3 Enter the value T' as the reading on the black substrate corresponding to the coating thickness T. ($T' = T + t_0$).

9.4 Find and encircle five pairs of points over the black and the white substrates, where the powder coating is at the specified thickness T.

9.5 Measure the reflectances of each pair of points and enter in the R_O and R_W columns of the table, then calculate the contrast ratio ($C_W = 100\ R_O/R_W$) for each pair.

NOTE 9—Some reflectance instruments can measure the contrast ratio directly. In that case, pair the equal-thickness points randomly for contrast ratio measurements and record values.

9.6 Calculate and record the mean contrast ratio C_W for each panel, and then the grand mean for all panels.

10. Procedure and Calculations—Test Method B, Film Thickness (T_{98}) at 98 % Contrast Ratio

10.1 Use Fig. 4 for entries in this test method.

10.2 Encircle five points in the coated black-substrate area at locations where the contrast ratio varies up to about 98 % as

Film Thickness (T_{98}) at 98% (0.98) Contrast Ratio
($T = T' - t_0$)

Coating ID: _____ Circle: mils µm

Color Description: _____ Reflectivity R_∞ _____ %

Gloss Description: _____ Laboratory: _____

Panel 1	t_0 =			T_{98} =	
Pair No.	T'	T	R_0	R_W	%C_W
1					
2					
3					
4					
5					
6					
7					
8					

Panel 2	t_0 =			T_{98} =	
Pair No.	T'	T	R_0	R_W	%C_W
1					
2					
3					
4					
5					
6					
7					
8					

Panel 3	t_0 =			T_{98} =	
Pair No.	T'	T	R_0	R_W	%C_W
1					
2					
3					
4					
5					
6					
7					
8					

Panel 4	t_0 =			T_{98} =	
Pair No.	T'	T	R_0	R_W	%C_W
1					
2					
3					
4					
5					
6					
7					
8					

Operator: _____ Date: _____ Mean T_{98} _____

FIG. 4 Work Table for Test Method B

recognized visually by familiarity with past results, or by comparison with a previously prepared visual standard.

10.3 Measure the thickness value T' of each of the five encircled points, and subtract t_0 from each value to obtain the true thickness T of the powder coating at those points.

10.4 For each of the points located in 10.3, locate and encircle a point of equal powder coating thickness in the white-substrate area.

NOTE 10—Since the gage is calibrated to zero on the white substrate, the gage reading here needs no correction.

10.5 For each pair of equal thickness points, measure and record the reflectances R_0 and R_W, then calculate and record $C_W = 100\ R_0/R_W$. Do not search for 98 % contrast ratio pairs.

NOTE 11—With instruments that can measure the contrast ratio directly, reflectances need not be measured.

10.6 Plot C_W versus film thickness (T) on suitable graph paper, (see Fig. 5) then draw the best-fit straight line, and select the best graph-point for T_{98}.

NOTE 12—Do not plot graph-points outside the contrast ratio range of 96.5 to 98.5 %. If the plotted points do not give an adequate indication of T_{98}, locate and plot additional equal thickness pairs.

10.7 Enter into the table the T_{98} value for each panel, and the grand mean for all panels.

11. Report

11.1 Report the following information:

11.2 Test Method A: Contrast ratio _____% at film thickness of _____µm (_____mils),

11.3 Test Method B: Film thickness (T_{98}) at 98 % Contrast Ratio _____µm (_____mils),

11.4 Reflectivity (R_∞) of the coating _____%,

11.5 General color and gloss description (for example, light green semi-gloss), and

11.6 Reflectometer Description—manufacturer, model, aperture size, and shape, bidirectional or spherical, and any other measurement parameters deemed significant.

12. Precision and Bias

12.1 *Precision*—In an inter-laboratory study of Test Methods A and B, operators in 5 different laboratories measured 3 test coatings differing in color and reflectivity. The coatings were applied in quadruplicate in accordance with the specified application procedure common to both methods, whereby each of the resultant 12 coated test panels presented a range of film thickness. The same panels were measured with Test Methods A and B.

12.1.1 *Test Method A—Percent Contrast Ratio at a Specified Film Thickness:* Two film thicknesses were specified for

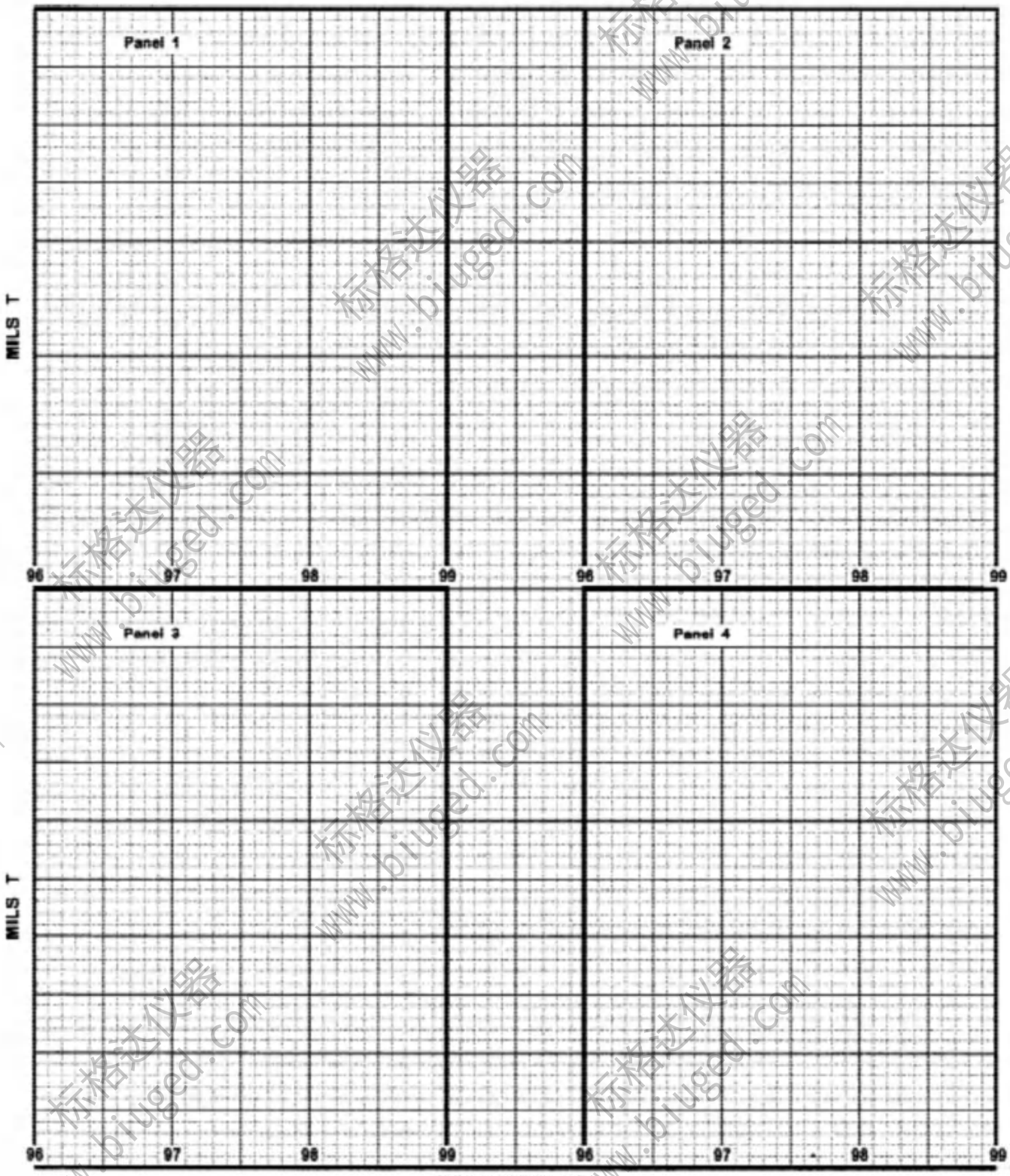


FIG. 5 Test Method B—Film Thickness at 98 % Contrast Ratio-Color

each color. The pooled intra- and inter-laboratory standard deviations were found to be those in Table 1, Columns 5 and 7. Based on these standard deviations the following criteria

TABLE 1 Precision of Test Method A: Percent Contrast Ratio, Absolute

					Intra-Laboratory		Inter-Laboratory	
(1)	(2)	(3)		(4)	(5)	(6)	(7)	(8)
Color	Reflectivity, %	Specified Film Thickness, µm	(mils)	Mean Contrast Ratio, %	Mean Standard Deviation, %	Maximum Acceptable Difference, %	Mean Standard Deviation, %	Maximum Acceptable Difference, %
Yellow	69	64	(2.5)	96.8	0.60	1.7	0.31	0.87
		76	(3.0)	97.7	0.36	1.0	0.25	0.70
White	85	30	(1.2)	95.0	0.49	1.4	0.75	2.1
		38	(1.5)	97.3	0.33	0.9	0.36	1.0
Blue	21	28	(1.1)	93.9	0.73	2.0	2.0	5.6
		36	(1.4)	97.0	0.51	1.4	0.81	2.3
Pooled values	. . .	. . .	. . .	. . .	0.50	1.4	0.74	2.1

should be used in judging, at the 95 % confidence level, the acceptability of results for Test Method A:

12.1.1.1 *Repeatability*—Results for 2 panels, each the mean of 5 readings, obtained by the same operator in the same laboratory, should be considered suspect if they differ by more than the MAD (maximum acceptable difference) shown in Column 6 of Table 1.

12.1.1.2 *Reproducibility*—Results obtained by 2 laboratories, each the mean of 4 panel results, should be considered suspect if they differ by more than the MAD shown in Column 8 of Table 1.

12.1.2 *Test Method B—Film Thickness (mils) at 98 % Contrast Ratio:* The pooled intra-laboratory and inter-laboratory coefficients of variation (COV) and resultant MAD values were found to be those in Table 2, Columns 4 and 6. Based on these COV's the following criteria should be used in judging, at the 95 % confidence level, the acceptability of results in Test Method B (see Note 13):

12.1.2.1 *Repeatability*—Results for 2 panels, each the mean of 5 readings, obtained by the same operator in the same laboratory, should be considered suspect if they differ, percent relative, by more than the MAD shown in Column 5 of Table 2.

12.1.2.2 *Reproducibility*—Results from 2 laboratories, each the mean of 4 test panels, should be considered suspect if they differ, percent relative, by more than the MAD shown in Column 7 of Table 2.

NOTE 13—Since the primary interest in film thickness variations is on a percentage basis, statistical calculations for Test Method B are based on the percent coefficient of variation (COV), which is the ratio of the standard deviation to the mean film thickness. When the maximum acceptable difference (MAD) is calculated from a coefficient of variation (COV), the difference between two absolute values is expressed as the percent of their mean, referred to as "percent relative". Thus, for two absolute values, *A* and *B*, their difference "percent relative" is as follows:

$$\frac{A-B}{(A+B)/2} \times 100 \quad (1)$$

12.2 *Bias*—The concept of bias is not applicable, because there is no other accepted method for measuring the hiding power of powder coatings more authoritative than this one.

13. Keywords

13.1 contrast ratio; hiding power; opacity; powder coatings

APPENDIX

(Nonmandatory Information)

X1. KUBELKA-MUNK STANDARDIZATION EQUATION

X1.1 The test method described herein, as with the powder coating institute (PCI) Test Method 3, does not provide for variations in the reflectance (*W*) of the white substrate area of the test panels. For more critical evaluations, the following equation may be employed to obtain contrast ratio values for Tables 1 and 2 that are standardized to a substrate reflectance of 80 % (0.80) as follows:

$$C_{0.80} = \frac{WR_0(1-0.80R_0)}{R_0(W-0.80) + 0.8\,R_w(1-WR_0)} \quad (X1.1)$$

In this equation all of the variables are expressed as decimal fractions. For practical usage, a computer solution would be required[8] (see CGSB 1-GP-71).

[8] Derived from Kubelka Equation 34, Kubelka, P. "New Contributions to the Optics of Light Scattering materials—Part 1" *Journal of the Optical Society of America*, Vol 38, 1948.

TABLE 2 Precision of Test Method B: Film Thickness, Percent Relative

				Intra-Laboratory		Inter-Laboratory	
(1)	(2)	(3)		(4)	(5)	(6)	(7)
Color	Reflectivity, %	Mean Film Thickness, µm	(mils)	Coefficient of Variation, %	Maximum Acceptable Difference, %	Coefficient of Variation, %	Maximum Acceptable Difference, %
Yellow	69	79	(3.1)	5.0	14.0	5.3	14.8
White	85	46	(1.8)	5.6	15.7	8.1	22.7
Blue	21	41	(1.6)	5.5	15.4	5.9	16.6
Pooled values	. . .	. . .	. . .	5.4	15.0	6.4	18.0