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Standard Guide for Testing Coil Coatings[1]

This standard is issued under the fixed designation D3794; 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 guide covers procedures for testing coil coatings. The test methods included are listed in Table 1. Where more than one test method is listed for the same characteristic, no attempt is made to indicate superiority of one method over another. Selection of test methods to be followed must be governed by the requirements in each individual case, together with agreement between the producer and user.

1.2 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only.

1.3 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B117 Practice for Operating Salt Spray (Fog) Apparatus
B368 Test Method for Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (CASS Test)
C1371 Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers
C1549 Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer
D522 Test Methods for Mandrel Bend Test of Attached Organic Coatings
D523 Test Method for Specular Gloss
D610 Practice for Evaluating Degree of Rusting on Painted Steel Surfaces
D660 Test Method for Evaluating Degree of Checking of Exterior Paints
D661 Test Method for Evaluating Degree of Cracking of Exterior Paints
D714 Test Method for Evaluating Degree of Blistering of Paints
D822 Practice for Filtered Open-Flame Carbon-Arc Exposures of Paint and Related Coatings
D823 Practices for Producing Films of Uniform Thickness of Paint, Coatings and Related Products on Test Panels
D870 Practice for Testing Water Resistance of Coatings Using Water Immersion
D968 Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive
D1005 Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers
D1014 Practice for Conducting Exterior Exposure Tests of Paints and Coatings on Metal Substrates
D1193 Specification for Reagent Water
D1200 Test Method for Viscosity by Ford Viscosity Cup
D1210 Test Method for Fineness of Dispersion of Pigment-Vehicle Systems by Hegman-Type Gage
D1212 Test Methods for Measurement of Wet Film Thickness of Organic Coatings
D1308 Test Method for Effect of Household Chemicals on Clear and Pigmented Coating Systems
D1474 Test Methods for Indentation Hardness of Organic Coatings
D1475 Test Method for Density of Liquid Coatings, Inks, and Related Products
D1654 Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments
D1729 Practice for Visual Appraisal of Colors and Color Differences of Diffusely-Illuminated Opaque Materials
D1735 Practice for Testing Water Resistance of Coatings Using Water Fog Apparatus
D1823 Test Method for Apparent Viscosity of Plastisols and Organosols at High Shear Rates by Extrusion Viscometer

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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.

D1824 Test Method for Apparent Viscosity of Plastisols and Organosols at Low Shear Rates
D2092 Guide for Preparation of Zinc-Coated (Galvanized) Steel Surfaces for Painting (Withdrawn 2008)[3]
D2196 Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational Viscometer
D2197 Test Method for Adhesion of Organic Coatings by Scrape Adhesion
D2244 Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates
D2247 Practice for Testing Water Resistance of Coatings in 100 % Relative Humidity
D2248 Practice for Detergent Resistance of Organic Finishes
D2369 Test Method for Volatile Content of Coatings
D2454 Practice for Determining the Effect of Overbaking on Organic Coatings
D2697 Test Method for Volume Nonvolatile Matter in Clear or Pigmented Coatings
D2794 Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)
D2803 Guide for Testing Filiform Corrosion Resistance of Organic Coatings on Metal
D3003 Test Method for Pressure Mottling and Blocking Resistance of Organic Coatings on Metal Substrates
D3134 Practice for Establishing Color and Gloss Tolerances
D3170 Test Method for Chipping Resistance of Coatings
D3278 Test Methods for Flash Point of Liquids by Small Scale Closed-Cup Apparatus
D3359 Test Methods for Rating Adhesion by Tape Test
D3361 Practice for Unfiltered Open-Flame Carbon-Arc Exposures of Paint and Related Coatings
D3363 Test Method for Film Hardness by Pencil Test
D3960 Practice for Determining Volatile Organic Compound (VOC) Content of Paints and Related Coatings
D4060 Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
D4138 Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means
D4141 Practice for Conducting Black Box and Solar Concentrating Exposures of Coatings
D4145 Test Method for Coating Flexibility of Prepainted Sheet
D4146 Test Method for Formability of Zinc-Rich Primer/Chromate Complex Coatings on Steel
D4147 Practice for Applying Coil Coatings Using Wire-Wound Drawdown Bars
D4212 Test Method for Viscosity by Dip-Type Viscosity Cups
D4214 Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films
D4287 Test Method for High-Shear Viscosity Using a Cone/Plate Viscometer
D4518 Test Methods for Measuring Static Friction of Coating Surfaces (Withdrawn 2000)[3]
D4585 Practice for Testing Water Resistance of Coatings Using Controlled Condensation
D4587 Practice for Fluorescent UV-Condensation Exposures of Paint and Related Coatings
D5031 Practice for Enclosed Carbon-Arc Exposure Tests of Paint and Related Coatings
D5178 Test Method for Mar Resistance of Organic Coatings
D5402 Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs
D5531 Guide for Preparation, Maintenance, and Distribution of Physical Product Standards for Color and Geometric Appearance of Coatings
D5723 Practice for Determination of Chromium Treatment Weight on Metal Substrates by X-Ray Fluorescence
D5796 Test Method for Measurement of Dry Film Thickness of Thin-Film Coil-Coated Systems by Destructive Means Using a Boring Device
D5894 Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)
D6093 Test Method for Percent Volume Nonvolatile Matter in Clear or Pigmented Coatings Using a Helium Gas Pycnometer
D6491 Practice for Evaluation of Aging Resistance of Pre-stressed Prepainted Metal In a Dry Heat Test
D6492 Practice for Detection of Hexavalent Chromium On Zinc and Zinc/Aluminum Alloy Coated Steel
D6578 Practice for Determination of Graffiti Resistance
D6665 Practice for Evaluation of Aging Resistance of Pre-stressed Prepainted Metal in a Boiling Water Test
D6695 Practice for Xenon-Arc Exposures of Paint and Related Coatings
D6906 Test Method for Determination of Titanium Treatment Weight on Metal Substrates by Wavelength Dispersive X-Ray Fluorescence
D6944 Practice for Determining the Resistance of Cured Coatings to Thermal Cycling
D7091 Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals
D7093 Test Method for Formability of Thin Film Organic Coatings on Steel Over a Biaxially Stretched Dome
D7376 Practice for Outdoor Evaluation of Wet Stack Storage Conditions on Coil-Coated Metals
D7639 Test Method for Determination of Zirconium Treatment Weight or Thickness on Metal Substrates by X-Ray Fluorescence
D7835 Test Method for Determining the Solvent Resistance of an Organic Coating Using a Mechanical Rubbing Machine
D7893 Guide for Corrosion Test Panel Preparation, Testing, and Rating of Coil-Coated Building Products
D7869 Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings

[3] The last approved version of this historical standard is referenced on www.astm.org.

D7897 Practice for Laboratory Soiling and Weathering of Roofing Materials to Simulate Effects of Natural Exposure on Solar Reflectance and Thermal Emittance
D8331 Test Method for Measurement of Film Thickness of Thin-Film Coatings by Non-Destructive Means Using Ruggedized Optical Interference
E70 Test Method for pH of Aqueous Solutions With the Glass Electrode
E84 Test Method for Surface Burning Characteristics of Building Materials
E284 Terminology of Appearance
E308 Practice for Computing the Colors of Objects by Using the CIE System
E376 Practice for Measuring Coating Thickness by Magnetic-Field or Eddy Current (Electromagnetic) Testing Methods
E408 Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques
E643 Test Method for Ball Punch Deformation of Metallic Sheet Material
E903 Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres
E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation
E1356 Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry
E1541 Practice for Specifying and Matching Color Using the Colorcurve System (Withdrawn 2007)[3]
E1545 Test Method for Assignment of the Glass Transition Temperature by Thermomechanical Analysis
E1640 Test Method for Assignment of the Glass Transition Temperature By Dynamic Mechanical Analysis
E1808 Guide for Designing and Conducting Visual Experiments
E1918 Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field
E1980 Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces
G7 Practice for Natural Weathering of Materials
G60 Practice for Conducting Cyclic Humidity Exposures
G85 Practice for Modified Salt Spray (Fog) Testing
G87 Practice for Conducting Moist SO_2 Tests
G90 Practice for Performing Accelerated Outdoor Weathering of Materials Using Concentrated Natural Sunlight
G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials
G151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources
G152 Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
G153 Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
G154 Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials
G155 Practice for Operating Xenon Arc Lamp Apparatus for Exposure of Materials

3. Terminology

3.1 *Definitions:*

3.1.1 *coil coating, n*—application of coatings or films to continuous metal coil stock.

3.1.2 *direct roller coat, n*—coating with the applicator or coating roll revolving in the same direction as the strip.

3.1.3 *metal pretreatment, n*—chemical treatment normally applied to the metal substrate prior to prime or finish coating.

3.1.3.1 *Discussion*—The treatment is designed to react with and modify the metal substrate to produce a surface suitable for coating or adhesive bonding.

3.1.4 *reverse roller coat, n*—coating with the applicator or coating roll revolving in a direction opposite to that of the strip.

3.2 The definitions given in Terminology G113 are applicable to this guide.

4. Significance and Use

4.1 This guide represents a collection of pertinent ASTM test methods used within the coil coatings industry. In the past coil coaters world wide depended on industry standards written by the National Coil Coating Association. That association, working cooperatively with ASTM, will no longer issue new, nor update old, standards.

5. General Requirements

5.1 All standard tests shall be made at 25 ± 3 °C (77 ± 25 °F) and 50 ± 5 % relative humidity, immediately after baking unless otherwise specified.

6. Sampling

6.1 The number of samples per unit of production shall be agreed upon between the producer and user.

7. Liquid Coating Properties

7.1 *Viscosity:*

7.1.1 It is common to measure the viscosity of coil coatings using an efflux technique (Ford or Zahn cup). This provides a simple, rapid technique for controlling the viscosity of a product, either in a paint production facility, or on-line at a coil coating facility. Coatings in the coil industry, however, cover a wide range of generic qualities, with many of them having non-Newtonian rheological characteristics. It is important, therefore, to consider the behavior of these coatings under different shear conditions, as well as measuring efflux viscosity. Some of the test methods require little expertise, where other test methods involve costly equipment and a high level of experience to run and interpret the rheological data.

7.1.2 *Efflux Viscosity*—Determine efflux viscosity in accordance with Test Method D4212 (Zahn cup) or D1200 (Ford cup).

7.1.3 *High-Shear Extrusion Viscosity*—Determine the high-shear extrusion viscosity for plastisols and organosols in accordance with Test Method D1823.

7.1.4 *Low-Shear Viscosity for Plastisols and Organosols*—Test in accordance with Test Method D1824.

7.1.5 *Rotational Viscosity*—Determine the viscosity with a rotational viscometer in accordance with Test Method D2196.

TABLE 1 List of Test Methods and Recommended Practices

	Section	ASTM Standard
Liquid Coatings Properties:	7	
Viscosity:	7.1	
Ford cup viscosity	7.1.2	D1200
Zahn cup viscosity	7.1.2	D4212
High-Shear extrusion viscometer	7.1.3	D1823
Plastisol and organosol low-shear viscosity	7.1.4	D1824
Rotational viscometer	7.1.5	D2196
Cone and Plate viscometer	7.1.6	D4287
Weight Solids	7.2	D2369
Volatile Content	7.2	D2369
Volume Solids	7.3	D2697, D6093
Fineness of dispersion	7.4	D1210
Density (weight per gallon)	7.5	D1475
VOC Determination	7.6	D3960
pH	7.7	E70
Flash Point	7.8	D3278
Metal Pretreatment:	8	
Preparation of galvanized steel for painting	8.2	D2092
Detecting Cr+6	8.3.1	D6492
X-ray fluorescence, chrome determination	8.3.2	D5723
X-ray fluorescence, titanium determination	8.3.3	D6906
X-ray fluorescence, zirconium determination	8.3.4	D7639
Panel Preparation:	9	
Wire-wound drawdown bars	9.4.1.1	D4147
Blade film applicator	9.4.1.2	D823
Wet film thickness	9.5	D1212
Material Properties of a Cured Coil Coating System:	10	
Dry film thickness (DFT)	10.1	
DFT, destructive methods	10.1.1	
DFT, micrometer	10.1.1.1	D1005
DFT, microscope	10.1.1.2	D4138
DFT, boring method	10.1.1.3	D5796
DFT, non-destructive methods	10.1.2	
DFT, eddy current, non-ferrous base	10.1.2.1	D7091, E376
DFT, magnetic flux, ferrous base	10.1.2.2	D7091, E376
DFT, ruggedized optical interference	10.1.2.3	D8331
Color:	10.2	
Glossary of color	10.2.1	E284
Preparation and control of color standards	10.2.1	D5531
Color and gloss tolerances	10.2.1	D3134
Conducting visual experiments	10.2.1	E1808
Color differences by visual evaluation	10.2.2	
Visual evaluation of color and color difference	10.2.2.1	D1729
Color differences by instrumental evaluation	10.2.3	
Color matching, color curve system	10.2.3	E1541
CIE color difference	10.2.3	E308
Obtaining special data	10.2.3	E1164
Calculation of color differences	10.2.3	D2244
Specular gloss measurement	10.3	D523
Hardness:	10.4	
Pencil hardness	10.4.1	D3363
Indentation hardness	10.4.2	D1474
Flexibility:	10.5	
Impact resistance	10.5.2	D2794
Mandrel bend	10.5.3	D522
T bends	10.5.4	D4145
Ball punch deformation	10.5.5	E643
Draw test	10.5.6	D4146, D7093
Adhesion:	10.6	
Cross hatch tape adhesion	10.6.2	D3359
Scrape adhesion	10.6.3	D2197
Degree of Cure:	10.7	
Glass transition, TMA	10.7.2	E1545
Glass transition, DMA	10.7.2	E1640
Glass transition, DSC	10.7.2	E1356
Solvent resistance	10.7.3	D5402
Solvent resistance, mechanical rub machine	10.7.3	D7835
Dry heat test	10.7.4	D6491
Boiling water test	10.7.5	D6665
Other tests:	10.8	
Pressure mottling/blocking resistance	10.8.1	D3003
Effect of overbaking	10.8.2	D2454

TABLE 1 *Continued*

	Section	ASTM Standard
Detergent resistance	10.8.3	D2248
Effect of household chemicals	10.8.4	D1308
Abrasion and mar resistance	10.8.5	
Taber abraser	10.8.5.1	D4060
Falling (sand) abrasive	10.8.5.2	D968
Mar resistance	10.8.5.3	D5178
Flame spread	10.8.6	E84
Chip resistance	10.8.7	D3170
Coefficient of friction	10.8.9	D4518
Resistance to thermal cycling	10.8.10	D6944
Graffiti resistance	10.8.11	D6578
Radiative Properties of Cured Coil Coating Systems:	11	
Solar Reflectance:	11.1	
Measuring solar reflectance of horizontal and low-slope surfaces in the field	11.1.1.1	E1918
Measuring solar reflectance in laboratory and field	11.1.1.2	C1549
Method for solar absorbance, reflectance, and transmittance	11.1.1.3	E903
Practice for calculating solar reflectance index of horizontal and low-sloped opaque surfaces	11.1.1.4	E1980
Laboratory soiling test to simulate natural exposure	11.1.1.5	D7897
Thermal emittance:	11.2	
Measuring hemispherical emittance	11.2.1.1	C1371
Measuring total normal emittance	11.2.1.2	E408
Weathering and Corrosion Resistance Properties of a Cured Coil Coating System:	12	
Real-time weathering:	12.1	
Conducting exterior weathering tests	12.1.1	D1014, D7893, G7
Chalk resistance	12.1.2.2	D4214
Degree of rusting	12.1.2.5	D610
Degree of blistering:	12.1.2.1	D714
Checking	12.1.2.3	D660
Cracking	12.1.2.4	D661
Corrosion creepage	12.1.2.6	D1654
Wet storage resistance	12.1.3.1	D7376
Accelerated corrosion and environmental resistance characteristics:	12.2	
Salt spray	12.2.1	B117
Water fog	12.2.2	D1735
100 % Relative humidity	12.2.2	D2247
Condensation humidity	12.2.3	D4585
Water immersion	12.2.4	D870
Cyclic salt spray	12.2.5	G85
Cyclic salt fog/UV condensation:	12.2.5	D5894
Cyclic humidity	12.2.5	G60
Moist SO_2 testing (Kesternich)	12.2.6	G87
Copper-accelerated salt spray (CASS)	12.2.7	B368
Filiform corrosion	12.2.8	D2803
Specification for reagent water	12.2.9	D1193
Accelerated weathering tests:	12.3	
Dew cycle (Unfiltered open-flame carbon arc)	12.3.2	D3361, G151
Filtered, open-flame carbon arc	12.3.3	D822, G151, G152
Fluorescent UV-condensation	12.3.4	D4587, G151, G154
Enclosed carbon arc	12.3.5	D5031, G153, G151
Xenon arc	12.3.6	G151, G155, D6695, D7869
Accelerated outdoor tests (black box, heated black box, Fresnel)	12.3.7	D4141, G90

7.1.6 *Cone and Plate Viscometer*—Determine the viscosity using a cone and plate viscometer in accordance with Test Method D4287.

7.2 *Weight Solids*—Determine the level of nonvolatile mass in accordance with Test Method D2369.

7.3 *Volume Solids*—Determine the level of nonvolatile volume in accordance with Test Method D2697 or D6093.

7.4 *Fineness of Dispersion*—Determine the fineness of grind of a coating in accordance with Test Method D1210.

7.5 *Density*—Determine the density (weight per gallon) in accordance with Test Method D1475.

7.6 *VOC*—Determine the VOC (volatile organic component) content in accordance with Practice D3960.

7.7 *pH*—Controlling the level of acidity or alkalinity (pH) in the pretreatment section of a coil line, as well as that of waterborne coatings, is important. Determine pH in accordance with Test Method E70.

7.8 *Flash Point*—Test the flash point of a coating in accordance with Test Methods D3278.

8. Metal Pretreatment

8.1 The successful performance of any coil-coated system is dependent on metal substrate preparation. Metal preparation in the coil coating industry usually consists of one of the following methodologies: clean, rinse, formation of conversion coating, rinse, post-treatment of conversion coating, and dry; or, clean, rinse, application of a roll-on pretreatment, and dry.

The metal pretreatment promotes maximum formability and adhesion of the organic coatings to the substrate, as well as promoting environmental exposure resistance, including anti-corrosive properties, of the coil coated system. Cleaners, conversion coating treatments, dried-in-place roll-on pretreatments, and post-treatments vary with the performance desired, the coating system used, and the metal substrate. Because there is an interdependency between the cleaning, pretreating, and post-treatment steps, in order to obtain acceptable performance, it is necessary that the reaction times, concentrations, temperatures, and application methods used in the laboratory be as close as possible to those encountered under production condition, and that both laboratory and production conditions be in strict accordance with the pretreatment suppliers' specifications.

8.2 In the case of zinc coated steel surfaces, Guide D2092, Methods A, B, C, D, and F illustrate the variety of pretreatments available.

8.3 *Coating Weight of Metal Pretreatment*—The one parameter to ensure that a substrate is properly cleaned and pretreated is the measurement of the level of pretreatment and post-treatment.

8.3.1 Determine the presence of hexavalent chromium on zinc and zinc/aluminum alloy coated steel in accordance with Practice D6492.

8.3.2 *X-ray Fluorescence*—Determine the chromium weight in accordance with Practice D5723.

8.3.3 *X-ray Fluorescence*—Determine the titanium weight in accordance with Test Method D6906.

8.3.4 *X-ray Fluorescence*—Determine the zirconium weight or thickness with Test Method D7639.

9. Panel Preparation

9.1 *Summary of Method*—This method includes substrate and pretreatment selection for application of coatings by wire wound draw-down bars on laboratory panels.

9.2 *Choice of Substrate*—The substrate to be coated, substrate size, gage, temper, alloy, and pretreatment to be used shall be agreed upon between the producer and user. Avoid using substrates that have been contaminated by handling.

9.3 *Degassing of Substrate*—Some galvanized substrates tend to absorb gasses on aging. To avoid blistering when the substrate is coated and baked it may be necessary to de-gas the substrate by heating and cooling to room temperature prior to application of the coating. The time and temperature of the degassing cycle shall be agreed upon between the producer and user.

9.4 *Drawdowns, Apparatus:*

9.4.1 *Stainless Steel Wire-wound Draw-down Bars,* (preferably 12.7 mm (½ in. in diameter to prevent bowing during application) are used to achieve dry film thickness up to 38 µ (1.5 mils). The choice of the specific drawdown bar is dependent on the dry film thickness required, the rheological properties of the coating, and the volume solids of the coating being tested. Other methods of applying thicker coating >38 µ (>1.5 mils) are available, such as a blade applicator.

9.4.1.1 *Drawdown Bars*—Prepare drawdowns in accordance with Practice D4147.

9.4.1.2 *Blade Film Applicator*—Prepare samples (at film thicknesses greater than >38 µ (>1.5 mils) in accordance with Practices D823.

9.5 *Wet Film Thickness*—Determine the wet thickness of an applied coating in accordance with Test Methods D1212.

9.6 *Bake Schedule*—Bake the panel at a time and temperature to meet a metal temperature range agreed upon between the producer and user. The critical parameter in this baking process is the "peak metal temperature." This term refers to the maximum temperature that the substrate has reached during the baking cycle. In addition to peak metal temperature, other baking conditions, which influence the long-term performance of a coil coating, are the oven air temperature, and the time in which the coated metal is exposed to the heat within the oven (also called "dwell time"). The peak metal temperature may be measured using infrared thermometry or a thermocouple, but the most common method is to utilize "temperature tapes." These self-adhesive strips contain temperature-sensitive indicators covering a range of temperatures.

10. Physical Properties of Cured Coil Coating System

10.1 *Dry Film Thickness (DFT)*—There are several methods used for determining the dry film thickness of a coil coating. The ability to measure the dry film thickness accurately is of utmost importance when one considers that the typical coil coating system (primer+topcoat) is often no more than 25-µ (1-mil) thick. It is always advisable to take at least three DFT measurements to obtain an average value of DFT. There are both non-destructive and destructive means of measuring film thickness for ferrous or aluminum substrates. Coatings applied to commercially available hot-dipped galvanized steel, zinc-aluminum, and other nonferrous alloys, may only be measured, due to the uneven nature of the alloy layer, by destructive means.

10.1.1 *Destructive Determination of Dry Film Thickness:*

10.1.1.1 *Micrometer*—Determine the DFT of a coil coating with a micrometer in accordance with Test Method D1005. The micrometer must be capable of reading to ≤0.0005 in. (0.05 mils).

10.1.1.2 *Microscope (Tooke Gage)*—Determine the DFT of a coil coating with a microscope in accordance with Test Method D4138.

10.1.1.3 *Boring Method*—Determine the DFT of a coil coating with a boring device in accordance with Test Method D5796.

10.1.2 *Non-Destructive Determination of Dry Film Thickness:*

10.1.2.1 *Eddy-Current*—Determine the DFT of a coil coating on aluminum in accordance with Test Method D7091 and Practice E376.

10.1.2.2 *Magnetic Flux*—Determine the DFT of a coil coating on a ferrous substrate in accordance with Test Method D7091 and Practice E376.

10.1.2.3 *Ruggedized Optical Interference*—Determine the film thickness over any metal substrate in accordance with Test Method D8331.

10.2 *Color:*

10.2.1 The color difference between two homogeneously colored opaque films may be determined by visual evaluation or by instrumental means. The color standard used shall be agreed upon between the producer and user. Terminology E284 provides a glossary of terms relating to the field of color. It is common to compare a color sample to a standard. Guide D5531 describes the control of standards, and Guide E1808 describes methods of conducting visual color experiments. Establish color and gloss tolerances in accordance with Practice D3134.

10.2.2 *Color Differences of Opaque Materials by Visual Evaluation:*

10.2.2.1 *Visual Evaluation*—Visual comparison of color is fast and often acceptable, although numerical values are not obtained. The referenced test method covers the spectral, photometric and geometric characteristics of light source, illumination and viewing conditions, size of specimens, and general procedures to be used in the visual evaluation of color differences, in accordance with Practice D1729.

10.2.2.2 *Metamerism*—Metamerism results when a sample and a standard have varying degrees of color difference under different light sources (for example, natural sunlight versus fluorescent lighting).

10.2.3 *Color Difference of Opaque Material by Instrumental Evaluation*—Color difference between a product and its standard can be determined from results of instrumental measurement. Measure products and color standards using Practices E308, E1164, or E1541. Compare color difference using Test Method D2244. Color tolerance is agreed upon between producer and user.

10.3 *Specular Reflectance:*

10.3.1 Specular reflectance in the coil industry is generally determined by readings at angles of 20° (also called "clarity"), 60° (also called "gloss"), or 85° (also called "sheen"). Determine specular reflectance in accordance with Test Methods D523. Establish gloss tolerances in accordance with Practice D3134.

10.4 *Hardness:*

10.4.1 *Pencil Hardness*—The pencil hardness of a coil coating is a fast and inexpensive method to assess a set of complex properties associated with a coil coating system. Whereas the intent is usually to measure the hardness and scratch resistance of the coil coating, the very nature of the test also assesses the adhesion of the coating to the underlying material (for example, primer, in the case of a two-coat system, or substrate, in the case of single-coat system). If a condition exists where the adhesion of the coating to the underlying layer is poor, it is common to observe an unusually low pencil hardness value. Also, the surface morphology and slip tendencies of the coating also contribute to the "pencil hardness" (that is, low-gloss surfaces allow the pencil lead to more readily dig into the coating, compared to a smooth, high-gloss coating). While this test continues to prove to be valuable, caution is urged whenever a reading is observed that appears to be too high or too low. One must always realize that the nature of this test is laden with operator variability. Also, the pencils used in this test method are controlled by the manufacturers for their "darkness" quality when used on white paper (since they are actually drafting pencils). The manufacturers do not control the pencils for any engineering properties that are associated with the strength of material (a coil coating in this case).

10.4.1.1 Determine hardness of a coil-coated material by the pencil hardness method in accordance with Test Method D3363.

10.4.2 *Indentation Hardness*—Indentation hardness is strictly a laboratory test, requiring specialized equipment and expert knowledge to interpret the results. Indentation hardness compared with the pencil hardness test, has the advantage of not being influenced by the effect of adhesion, and, therefore, may be more effective in better describing the degree of cure of a coating.

10.4.2.1 Determine the indentation hardness of a coil-coated material in accordance with Test Methods D1474, using either Method A (Knoop indentation hardness) or Method B (Pfund indentation hardness).

10.5 *Flexibility:*

10.5.1 There are several methods to measure the flexibility of a coil coating. All give indications of the fabrication properties of the coatings, and all involve evaluating the response of the coating under tension, elongation, or compression, or both. The rate of deformation is often critical in the assessment of the flexibility qualities of the coil coating system. The most common tests are impact, wedge bend, T-bends, and conical mandrel flexibility.

10.5.2 *Impact*—Impact testing involves a rapid deformation process. Determine the impact resistance of a coil-coated material in accordance with Test Method D2794.

10.5.3 *Conical Mandrel*—Conical mandrel testing involves a slow deformation, graduated bend-radii operation. Determine the conical mandrel flexibility in accordance with Test Methods D522.

10.5.4 *T-Bends*—T-bend flexibility involves a slow deformation operation. Determine the T-bend performance of coil materials in accordance with Test Method D4145.

10.5.5 *Ball Punch Deformation*—Determine performance of a coil coating associated with ball punch deformation in accordance with Test Method E643.

10.5.6 *Stretch Draw Test*—Determine the ability of a coil coating to withstand the compressive and extension forces involved in a drawing application in accordance with Test Methods D4146 and D7093.

10.6 *Adhesion:*

10.6.1 The level of adhesion of a coating to a substrate or to another coating (such as a primer) is a very difficult parameter to measure. Often, the cohesive force of the coating acts in such a way as to make the adhesion of the coating appear to be at an acceptable limit, for example, a coating that has low cohesive strength breaks apart as you attempt to remove it, and the inability to remove the coating from the substrate is considered to demonstrate acceptable adhesion. On the other hand, coatings with very high cohesive strength may be more likely to peel off a substrate, since such coatings are tough enough that they do not tear apart as you attempt to remove them. No one test device is commercially available to the coil coating industry that has the capability of measuring the