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# Standard Guide for Testing Coil Coatings[1]

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## 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 the 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 and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*

B 117 Practice for Operating of Salt Spray (Fog) Apparatus[2]
B 368 Test Method for Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (Cass Test)[3]
D 522 Test Methods for Mandrel Bend Test of Attached Organic Coatings[4]
D 523 Test Methods for Specular Gloss[4]
D 610 Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces[5]
D 660 Test Method for Evaluating Degree of Checking Exterior Paints[4]
D 661 Test Method for Evaluating Degree of Cracking of Exterior Paints[4]
D 714 Test Method for Evaluating Degree of Blistering of Paints[4]
D 822 Practice for Conducting Tests on Paint and Related Coatings and Materials Using Filtered Open-Flame Carbon-Arc Apparatus[4]
D 823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Tests Panels[4]
D 870 Practice for Testing Water Resistance of Coatings Using Water Immersion[4]
D 968 Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive[4]
D 1005 Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers[4]
D 1014 Practice for Conducting Exterior Exposure Tests of Paints on Steel[4]
D 1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base[4]
D 1193 Specification for Reagent Water[6]
D 1200 Test Method for Viscosity by Ford Viscosity Cup[4]
D 1210 Test Method for Fineness of Dispersion of Pigment-Vehicle Systems by Hegman-Type Gage[4]
D 1212 Test Methods for Measurement of Wet Film Thickness of Organic Coatings[4]
D 1308 Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes[5]
D 1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base[4]
D 1474 Test Methods for Indentation Hardness of Organic Coatings[4]
D 1475 Test Method for Density of Paint, Varnish, Lacquer, and Related Products[4]
D 1654 Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments[4]
D 1729 Practice for Visual Appraisal of Colors and Color Differences of Diffusely-Illuminated Opaque Materials[4]
D 1735 Practice for Testing Water Resistance of Coatings Using Water Fog Apparatus[4]
D 1823 Test Method for Apparent Viscosity of Plastisols and Organosols at High Shear Rates by Extrusion Viscometer[7]
D 1824 Test Method for Apparent Viscosity of Plastisols and Organosols at Low Shear Rates by Brookfield Viscometer[7]
D 2092 Guide for Treatment of Zinc-Coated (Galvanized) Steel Surfaces for Painting[5]
D 2196 Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational (Brookfield) Viscometer[4]

[1] This specification is under the jurisdiction of ASTM Committee D 1 on Paint and Related Coatings, Materials, and Applications, and is the direct responsibility of Subcommittee D01.53 on Coil Coated Metal.

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[2] *Annual Book of ASTM Standards*, Vol 03.02.
[3] *Annual Book of ASTM Standards*, Vol 02.05.
[4] *Annual Book of ASTM Standards*, Vol 06.01.
[5] *Annual Book of ASTM Standards*, Vol 06.02.
[6] *Annual Book of ASTM Standards*, Vol 11.01.
[7] *Annual Book of ASTM Standards*, Vol 08.01.

D 2197 Test Method for Adhesion of Organic Coatings by Scrape Adhesion[4]
D 2244 Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates[4]
D 2247 Practice for Testing Water Resistance of Coatings in 100 % Relative Humidity[4]
D 2248 Practice for Detergent Resistance of Organic Finishes[4]
D 2369 Test Method for Volatile Content of Coatings[4]
D 2454 Practice for Determining the Effect of Overbaking on Organic Coatings[4]
D 2697 Test Method for Volume Nonvolatile Matter in Clear or Pigmented Coatings[4]
D 2794 Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)[4]
D 2803 Guide for Testing Filiform Corrosion Resistance of Organic Coatings on Metal[4]
D 3003 Test Method for Pressure Mottling and Blocking Resistance of Organic Coatings on Metal Substrates[5]
D 3134 Practice for Establishing Color and Gloss Tolerances[4]
D 3170 Test Method for Chipping Resistance of Coatings[5]
D 3278 Test Methods for Flash Point of Liquids by Small Scale Closed-Cup Apparatus[4]
D 3359 Test Methods for Measuring Adhesion by Tape Test[4]
D 3361 Practice for Operating Light- and Water-Exposure Apparatus (Unfiltered Open-Flame Carbon-Arc Type) for Testing Paint, Varnish, Lacquer, and Related Products Using the Dew Cycle[4]
D 3363 Test Method for Film Hardness by Pencil Test[4]
D 3960 Practice for Determining Volatile Organic Compound (VOC) Content of Paints and Related Coatings[4]
D 4060 Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser[4]
D 4138 Test Method for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive Means[5]
D 4141 Practice for Conducting Accelerated Outdoor Exposure Tests of Coatings[4]
D 4145 Test Method for Coating Flexibility of Prepainted Sheet[5]
D 4146 Test Method for Formability of Zinc-Rich Primer/Chromate Complex Coatings on Steel[5]
D 4147 Practice for Applying Coil Coatings Using the Wire-Wound Drawdown Bar[5]
D 4212 Test Method for Viscosity by Dip-Type Viscosity Cups[4]
D 4214 Test Methods for Evaluating Degree of Chalking of Exterior Paint Films[4]
D 4287 Test Method for High-Shear Viscosity Using the ICI Cone/Plate Viscometer[4]
D 4518 Test Methods for Measuring Static Friction of Coating Surfaces[8]
D 4585 Practice for Testing Water Resistance of Coatings Using Controlled Condensation[4]
D 4587 Practice for Conducting Tests on Paint and Related Coatings and Materials Using a Fluorescent UV-Condensation Light- and Water-Exposure Apparatus[4]
D 5031 Practice for Conducting Tests on Paints and Related Coatings and Materials Using Enclosed Carbon-Arc Light and Water Exposure Apparatus[4]
D 5178 Test Method for Mar Resistance of Organic Coatings[4]
D 5402 Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs[5]
D 5531 Guide for Preparation, Maintenance and Distribution of Physical Product Standards for Color and Geometric Appearance of Coatings[4]
D 5723 Practice for Determination of Chromium Treatment Weight on Metal Substrates by X-Ray Fluorescence[5]
D 5796 Test Method for Measurement of Dry Film Thickness of Thin Film Coil-Coated Systems by Destructive Means Using a Boring Device[5]
D 5894 Practice for Cyclic Salt Fog-UV Exposure of Painted Metal (Alternating Exposure in a Fog/Dry Cabinet and UV/Condensation Cabinet)[4]
D 6093 Test Method for Percent Volume Nonvolatile Matter in Clear or Pigmented Coatings Using a Helium Gas Pycnometer[4]
D 6491 Practice for Evaluation of Aging Resistance of Prestressed Prepainted Metal in a Dry Heat Test[5]
D 6492 Practice for Detection of Hexavalent Chromium On Zinc and Zinc/Aluminum Alloy Coated Steel[5]
E 70 Test Method for pH of Aqueous Solutions with the Glass Electrode[9]
E 84 Test Method for Surface Burning Characteristics of Building Materials[10]
E 284 Terminology of Appearance[4]
E 308 Practice for Computing the Colors of Objects by Using the CIE System[4]
E 408 Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques[11]
E 643 Test Method for Ball Punch Deformation of Metallic Sheet Material[12]
E 903 Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres[13]
E 1164 Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation[4]
E 1356 Test Method for Glass Transition Temperatures by Differential Scanning Calorimetry or Differential Thermal Analysis[14]
E 1541 Practice for Specifying and Matching Color Using the Colorcurve System[4]
E 1545 Test Method for Assignment of the Glass Transition Temperature by Thermomechanical Analysis[14]
E 1640 Test Method for Assignment of the Glass Transition Temperature by Dynamic Mechanical Analysis[14]

[8] Discontinued; see *1999 Annual Book of ASTM Standards*, Vol 06.01.

[9] *Annual Book of ASTM Standards*, Vol 15.05.
[10] *Annual Book of ASTM Standards*, Vol 04.07.
[11] *Annual Book of ASTM Standards*, Vol 15.03.
[12] *Annual Book of ASTM Standards*, Vol 03.01.
[13] *Annual Book of ASTM Standards*, Vol 12.02.
[14] *Annual Book of ASTM Standards*, Vol 14.02.

E 1808 Guide for Designing and Conducting Visual Experiments[4]
E 1918 Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field[10]
G 7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials[15]
G 60 Test Method for Conducting Cyclic Humidity Tests[2]
G 85 Practice for Modified Salt Spray (Fog) Testing[2]
G 87 Practice for Conducting Moist $SO_2$ Tests[2]
G 90 Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight[15]
G 113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials[15]
G 151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources[15]
G 152 Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials[15]
G 153 Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials[15]
G 154 Practice for Operating Fluorescent Light Apparatus for UV Exposure of Nonmetallic Materials[15]
G 155 Practice for Operating Xenon Arc Light Apparatus for Exposure of Nonmetallic Materials[15]
G 159 Tables for References Solar Spectral Irradiance at Air Mass 1.5: Direct Normal and Hemispherical for a 37° Tilted Surface[15]

## 3. Terminology

3.1 *Definitions:*

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

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

3.1.3 *metal pretreatment*—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*—coating with the applicator or coating roll revolving in a direction opposite to that of the strip.

3.2 The definitions given in Terminology G 113 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 Coaters 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.

[15] *Annual Book of ASTM Standards*, Vol 14.04.

**TABLE 1 List of Test Methods and Recommended Practices**

| | Section | ASTM Standard |
|---|---|---|
| Liquid Coatings Properties: | | |
| Viscosity: | 7.1 | |
| Ford cup viscosity | 7.1.2 | D 1200 |
| Zahn cup viscosity | 7.1.2 | D 4212 |
| High-Shear extrusion viscometer | 7.1.3 | D 1823 |
| Plastisol and organosol low-shear viscosity | 7.1.4 | D 1824 |
| Brookfield-type viscometer | 7.1.5 | D 2196 |
| Cone and Plate viscometer | 7.1.6 | D 4287 |
| Weight Solids | 7.2 | D 2369 |
| Volatile Content | 7.2 | D 2369 |
| Volume Solids | 7.3 | D 2697, D 6093 |
| Fineness of dispersion | 7.4 | D 1210 |
| Density (weight per gallon) | 7.5 | D 1475 |
| VOC Determination | 7.6 | D 3960 |
| pH | 7.7 | E 70 |
| Flash Point | 7.8 | D 3278 |
| Metal Pretreatment: | | |
| Preparation of galvanized steel for painting | 8.2 | D 2092 |
| Detecting Cr+6 | 8.3.1 | D 6492 |
| X-ray fluorescence, chrome determination | 8.3.2 | D 5723 |
| Panel Preparation: | | |
| Wire-wound drawdown bars | 9.4.1.1 | D 4147 |
| Blade film applicator | 9.4.1.2 | D 823 |
| Wet film thickness | 9.5 | D 1212 |
| Material Properties of a Cured Coil Coating System: | 10 | |

TABLE 1 *Continued*

| | Section | ASTM Standard |
|---|---|---|
| Dry film thickness (DFT) | 10.1 | . . . |
| DFT, destructive methods | 10.1.1 | . . . |
| DFT, micrometer | 10.1.1.1 | D 1005 |
| DFT, microscope | 10.1.1.2 | D 4138 |
| DFT, boring method | 10.1.1.3 | D 5796 |
| DFT, non-destructive methods | 10.1.2 | . . . |
| DFT, eddy current, non-ferrous base | 10.1.2.1 | D 1400 |
| DFT, magnetic flux, ferrous base | 10.1.2.2 | D 1186 |
| Color | 10.2 | |
| Glossary of color | 10.2.1 | E 284 |
| Preparation and control of color standards | 10.2.1 | D 5531 |
| Color and gloss tolerances | 10.2.1 | D 3134 |
| Conducting visual experiments | 10.2.1 | E 1808 |
| Color differences by visual evaluation | 10.2.2 | . . . |
| Visual evaluation of color and color difference | 10.2.2.1 | D 1729 |
| Color differences by instrumental evaluation | 10.2.3 | . . . |
| Color matching, color curve system | 10.2.3 | E 1541 |
| CIE color difference | 10.2.3 | E 308 |
| Obtaining spectral data | 10.2.3 | E 1164 |
| Calculation of color differences | 10.2.3 | D 2244 |
| Specular gloss measurement | 10.3 | D 523 |
| Hardness | 10.4 | |
| Pencil hardness | 10.4.1 | D 3363 |
| Indentation hardness | 10.4.2 | D 1474 |
| Flexibility | 10.5 | — |
| Impact resistance | 10.5.2 | D 2794 |
| Mandrel bend | 10.5.3 | D 522 |
| T bends | 10.5.4 | D 4145 |
| Ball punch deformation | 10.5.5 | E 643 |
| Draw test | 10.5.6 | D 4146 |
| Adhesion: | 10.6 | |
| Cross hatch tape adhesion | 10.6.2 | D 3359 |
| Scrape adhesion | 10.6.3 | D 2197 |
| Degree of Cure: | | |
| Glass transition TMA | 10.7.2 | E 1545 |
| Glass transition, DMA | 10.7.2 | E 1640 |
| Glass transition, DSC | 10.7.2 | E 1356 |
| Solvent resistance | 10.7.3 | D 5402 |
| Dry heat test | 10.7.4 | D 6491 |
| Other Tests: | 10.8 | |
| Pressure mottling/blocking resistance | 10.8.1 | D 3003 |
| Effect of overbaking | 10.8.2 | D 2454 |
| Detergent resistance | 10.8.3 | D 2248 |
| Effect of household chemicals | 10.8.4 | D 1308 |
| Abrasion and mar Resistance | 10.8.5 | |
| Taber abraser | 10.8.5.1 | D 4060 |
| Falling (sand) abrasive | 10.8.5.2 | D 968 |
| Mar resistance | 10.8.5.3 | D 5178 |
| Flame spread | 10.8.6 | E 84 |
| Chip resistance | 10.8.7 | D 3170 |
| Coefficient of friction | 10.8.9 | D 4518 |
| Weathering and Corrosion Resistance Properties of a Cured Coil Coating System: | | |
| Real-time weathering | 11.1 | |
| Conducting exterior weathering tests | 11.1.1 | D 1014, G 7 |
| Chalk resistance | 11.1.2.2 | D 4214 |
| Degree of rusting | 11.1.2.5 | D 610 |
| Degree of blistering | 11.1.2.1 | D 714 |
| Checking | 11.1.2.3 | D 660 |
| Cracking | 11.1.2.4 | D 661 |
| Corrosion creepage | 11.1.2.6 | D 1654 |
| Accelerated corrosion and environmental resistance characteristics | 11.2 | — |
| Salt spray | 11.2.1 | B 117 |
| Water fog | 11.2.3 | D 1735 |
| 100 % Relative humidity | 11.2.3 | D 2247 |
| Condensation humidity | 11.2.4 | D 4585 |
| Water immersion | 11.2.5 | D 870 |
| Cyclic salt spray | 11.2.6 | G 85 |
| Cyclic salt fog/UV condensation | 11.2.6 | D 5894 |
| Cyclic humidity | 11.2.6 | G 60 |
| Moist $SO_2$ testing (Kesternich) | 11.2.7 | G 87 |
| Copper-accelerated salt spray (CASS) | 11.2.8 | B 368 |
| Filiform corrosion | 11.2.9 | D 2803 |
| Specification for reagent water | 11.2.9 | D 1193 |
| Accelerated weathering tests | 11.3 | |

TABLE 1 *Continued*

| | Section | ASTM Standard |
|---|---|---|
| Dew cycle (Unfiltered open-flame Carbon arc) | 11.3.2 | D 3361, G 151 |
| Filtered, open-flame carbon arc | 11.3.3 | D 822, G 151, G 152 |
| Fluorescent UV-condensation | 11.3.4 | D 4587, G 151, G 154 |
| Enclosed carbon arc | 11.3.5 | D 5031, G 153, G 151 |
| Xenon arc | 11.3.6 | G 151, G 155 |
| Accelerated outdoor tests (black box, heated black box, Fresnel) | 11.3.7 | D 4141, G 7, G 90 |
| Solar reflectance | 11.4 | |
| Measuring solar reflectance of horizontal and low-slope surfaces in the field | 11.4.1 | E 1918 |
| Measuring total normal emittance | 11.4.2 | E 408 |
| Method for solar absorbance, reflectance, and transmittance | 11.4.3 | E 903 |
| Tables for references solar spectral irradiance at air mass 1.5: direct normal and hemispherical for a 37° tilted surface | 11.4.4 | G 159 |

## 7. Liquid Coatings 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 nonNewtonian 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 Methods D 4212 (Zahn cup) or D 1200 (Ford cup).

7.1.3 *High-Shear Extrusion Viscosity*—Determine the high-shear extrusion viscosity for plastisols and organosols in accordance with Test Method D 1823.

7.1.4 *Low-Shear Viscosity for Plastisols and Organosols*—Test in accordance with Test Method D 1824.

7.1.5 *Brookfield-type Viscosity*—Determine the Brookfield viscosity with a rotational viscometer in accordance with Test Method D 2196.

7.1.6 *Cone and Plate Viscometer*—Determine the viscosity using a cone and plate viscometer in accordance with Test Method D 4287.

7.2 *Weight Solids*—Determine the level of nonvolatile mass in accordance with Test Method D 2369.

7.3 *Volume Solids*—Determine the level of nonvolatile volume in accordance Test Method D 2697 or D 6093.

7.4 *Fineness of Dispersion*—Determine the fineness of grind of a coating in accordance with Test Method D 1210.

7.5 *Density*—Determine the density (weight per gallon) in accordance with Test Method D 1475.

7.6 *VOC*—Determine the VOC (volatile organic component) content in accordance with Practice D 3960.

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 E 70.

7.8 *Flash Point*—Test the flash point of a coating in accordance with Test Methods D 3278.

## 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, posttreatment 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 anticorrosive properties, of the coil coated system. Cleaners, conversion coating treatments, dried-in-place roll-on pretreatments, and posttreatments vary with the performance desired, the coating system used, and the metal substrate. Because there is an interdependency between the cleaning, pretreating, and posttreatment 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 D 2092, 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 posttreatment.

8.3.1 Determine the presence of hexavalent chromium on zinc and zinc/aluminum alloy coated steel in accordance with Practice D 6492.

8.3.2 *X-ray Fluorescence*—Determine the chromium level in accordance with Practice D 5723.

## 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 coatings >38 µ (>1.5 mils) are available, such as a blade applicator.

9.4.1.1 *Drawdown Bars*—Prepare drawdowns in accordance with Practice D 4147.

9.4.1.2 *Blade Film Applicator*—Prepare samples (at film thicknesses greater than 38 µ (1.5 mils) in accordance with Practices D 823.

9.5 *Wet Film Thickness*—Determine the wet thickness of an applied coating in accordance with Test Methods D 1212.

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 and 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 D 1005. The micrometer must be capable of reading to ≤0.00005 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 D 4138.

10.1.1.3 *Boring Method*—Determine the DFT of a coil coating with a boring device in accordance with Test Method D 5796[16].

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 D 1400.

10.1.2.2 *Magnetic Flux*—Determine the DFT of a coil coating on a ferrous substrate in accordance with Test Method D 1186.

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 E 284 provides a glossary of terms relating to the field of color. It is common to compare a color sample to a standard. Guide D 5531 describes the control of standards, and Guide E 1808 describes methods of conducting visual color experiments. Establish color and gloss tolerances in accordance with Practice D 3134.

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 D 1729.

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 E 308, E 1164, or E 1541. Compute color difference using Test Method D 2244. 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 D 523. Establish gloss tolerances in accordance with Practice D 3134.

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

[16] The sole source of supply of a suitable device known to the committee at this time is the DJH Designs, 2366 Wyecroft Rd., Unit D4, Oakville, Ontario Canada L6L 6M1. 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.

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 D 3363.

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 D 1474, 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 D 2794.

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 D 522.

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 D 4145.

10.5.5 *Ball Punch Deformation*—Determine the performance of a coil coating associated with ball punch deformation in accordance with Test Method E 643.

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 Method D 4146.

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 inherent adhesive attraction of a coating to another surface, but the following test methods are commonly used and felt to indicate the level of "adhesion." As already stated, these test methods are actually measuring certain aspects of both adhesion and cohesive strength, and it is common that a combination of these tests, in conjunction with tests for hardness and flexibility, are used to establish a standard level of "adhesion."

10.6.2 *Cross Hatch Tape Adhesion*—Determine the cross hatch tape adhesion of a coating in accordance with Test Methods D 3359.

10.6.3 *Scrape Adhesion*—Determine the level of scrape adhesion in accordance with Test Method D 2197.

10.7 *Degree of Cure (Polymeric Properties)*:

10.7.1 Most coil coatings are thermally set, and are converted from a liquid, uncrosslinked polymeric state to a solid, highly crosslinked polymeric state during the curing cycle in the baking oven. Many such coatings are composed of polymers that are considered "glassy" (somewhat hard and brittle) at normal operating temperatures. Such polymeric systems usually undergo a conversion at some temperature, where the inherent characteristics of the polymers change from the glassy state to a more rubbery state. This temperature is known as the glass transition temperature ($T_g$). The number of crosslinks that have been formed during the curing process (known as "crosslink density") affects many of the material properties stated in this guide. While it is possible, with a great deal of work, to determine the actual crosslink density of a cured coating, it is seldom necessary. Instead, a combination of material properties is usually suitable to determine that the level of crosslinking has taken place in such a fashion that it will result in suitable properties.

10.7.2 *Glass Transition Temperature*—An important parameter of an organic polymer is its glass transition temperature. While a specific $T_g$ value is often stated, the actual glassy-to-rubbery transition occurs over a temperature range (usually a few degrees Celsius). Care must be taken when interpreting glass transition temperature data. While it is common to test a coated sample (organic coating applied on a metal substrate), and the $T_g$ data is often described as representing the $T_g$ of the topcoat, most coil coatings are two-coat systems (primer+topcoat) and the primer layer can affect the $T_g$ of the system. Interaction of the pretreatment with the coating system may also influence the $T_g$.

10.7.2.1 Determine the glass transition temperature of a coil coating in accordance with Test Methods E 1545 (thermomechanical analysis), E 1640 (dynamic mechanical analysis), or E 1356 (differential scanning calorimetry).

NOTE 1—It would not be unusual for a single coated panel to yield three different $T_g$ values when determined by the three preceding test methods. For this reason, it is usually helpful to think of the $T_g$ as occurring somewhere within a range of temperatures, rather than as being an absolute value.

10.7.3 *Solvent Resistance*—In many coil coating systems, as the degree of cure increases, the resistance of the coating to dissolving in a particular solvent also increases. Determine the solvent resistance of a coating in accordance with Practice D 5402.

10.7.4 *Dry Heat Resistance*—Determine the resistance to the aging of prestressed prepainted metal in accordance to Practice D 6491.

10.8 *Other Tests*:

10.8.1 *Pressure Marking (Mottling) and Blocking*—Precoated coils are wound under tension, and may be stacked "eye-horizontal," that is, like a doughnut standing on it edge. Some coatings will "mark" or "mottle" (subtle surface deformation) as a result of the pressure to which the coating is subjected. Under certain circumstances, the precoated coils may even display a certain level of sticking (of a topcoat, on the topside of the coil, to the backer, on the backside of the coil), which may prove to be an innocuous effect, or may result in certain substantive problems (for example, the removal and transfer on one coating, say, the topcoat onto the backer). Determine the pressure marking and blocking resistance of coil-coated materials in accordance with Test Method D 3003.

10.8.2 *Overbake*—While the coil coating process is essentially a continuous, steady-state process, there are occasions when the time that a coating spends in the oven may be extended over the normal operating parameters. Determine the effect of overbaking a coil-coating material in accordance with Practice D 2454.

10.8.3 *Detergent Resistance*—Coil coatings are often used in the home laundry industry, where it is common for the prepainted system to be exposed to common laundry detergents. Determine the detergent resistance of an organic coating for the appliance industry in accordance with Practice D 2248.

10.8.4 *Stain Resistance*—Coil coatings are used extensively in the appliance industry, and establishing the resistance of a coil coating to common household chemicals is required. Determine the stain resistance and effect of household chemicals on a coil-coated finish in accordance with Test Method D 1308.

10.8.5 *Mar and Abrasion Resistance*—Abrasion resistance is another complex material property that is not easily measured. A coating may undergo wear (where the coating is rubbed away, and eventually the underlying material can be seen), or it may be scratched repeatedly, such that the coating is removed. Scratching may occur on a macroscopic level (where the damage is evident to the naked eye) or on a microscopic level (where the microscopic scratches may not be easily seen and may occur over a period of time before the damage is evident). Wear resistance and scratch resistance, therefore, are different properties, but both are often subsumed under the heading "abrasion resistance." Since wear and abrasion resistance parameters may be difficult to distinguish, the reader is advised to refer to each of the following tests with the specific language suggested.

10.8.5.1 *Taber Abraser Resistance*—This device produces thousands of microscopic cuts in the surface of a coating, and may actually be measuring the toughness of coating more than its abrasion resistance. Determine a coating's Taber abraser resistance properties in accordance with Test Method D 4060.

10.8.5.2 *Falling Abrasive Resistance*—Determine a coating's resistance to falling abrasive in accordance with Test Methods D 968.

NOTE 2—This test has not been shown to have any relationship to typical conditions to which a coating is exposed during its service life.

10.8.5.3 *Mar Resistance*—Determine a coating's resistance to marring in accordance with Test Method D 5178.

10.8.6 *Flame Spread*—Determine the flame spread characteristics of a coating in accordance with Test Method E 84.

10.8.7 *Chip Resistance*—Determine the chip resistance of a coating in accordance with Test Method D 3170.

10.8.8 *Elastic Memory*—All polymers under stress have some tendency to retract to their original orientation (that is, before strain was applied), a property sometimes referred to as "elastic memory." The evaluation of this property can be accelerated by subjecting the coated/stressed material to heat, which is described as "dry-heat resistance" (when the heat source is a hot oven) or "boiling water resistance" (when the coated/stressed sample is immersed in boiling water). This is a particularly important property to assess, since most coil coated systems receive some form of fabrication.

10.8.9 *Coefficient of Friction*—Determine the coefficient of friction of a coil coating in accordance with Test Methods D 4518.

## 11. Weathering and Corrosion Resistance Properties of a Cured Coil Coating System

11.1 *Real-Time Weathering*:

11.1.1 While laboratory accelerated tests can be used to assist in the prediction of weathering performance, such methods used solely, may actually lead to misleading conclusions regarding the prediction of outdoor performance. For this reason, actual outdoor exposure performed in accordance with Practice D 1014, and G 7, is required to determine the durability of exterior coil coatings to the outdoor environment. The extensive usage of coil coated paint systems in the building products and construction markets, and the durability and liability connected with these systems, is so varied that no one set of conditions (duration, location, and manner of exposure) can be given in this guide to cover all situations. These conditions, as well as the type of substrate, pretreatment, bake schedule, etc., should be agreed upon between the producer and the user. For this reason, it is recommended that real-time exposure testing be conducted in each of the environments to which the coil coating system will be exposed. This is not a simple task, since so many environments, and many more microenvironments, exist around the world. Because outdoor weather conditions vary from season to season, and from year to year, outdoor tests, including those referred to as "accelerated," cannot be used to establish absolute performance ratings for coatings. The procedures should only be used for comparing the relative performance of coatings exposed at the same time and at the same location. Additionally, each exposure series should contain one or more control specimens to act as comparison standards, and to provide a means for determining the severity of the exposure conditions encountered by the series. For best results, there should be at least two controls differing significantly in their durability.

11.1.2 Several properties should be evaluated periodically or at time intervals agreed upon between the producer and user in accordance with the following test methods:

11.1.2.1 *Blistering*—Test Method D 714.

11.1.2.2 *Chalking*—Test Method D 4214.

11.1.2.3 *Checking*—Test Method D 660.

11.1.2.4 *Cracking*—Test Method D 661.

11.1.2.5 *Rusting*—Method D 610.

11.1.2.6 *Corrosion*—Test Method D 1654

11.2 *Accelerated Corrosion and Environmental Resistance Characteristics:*

11.2.1 *Salt Spray Resistance*—Salt spray standard testing of coatings may be helpful in determining the general resistance to failure in service under conditions of constant high humidity and exceptionally high salt concentrations. There is wide recognition, however, that salt spray testing does not correlate with real-time test results in the majority of industries, applications, and service conditions. The selection of substrate, pretreatment, the coating system, the manner in which the coating is scribed, the location or position of the panels within the cabinet, the length of the standard test, the inspection of panels and method of reporting results, must be agreed upon between the producer and user. Test for salt spray resistance in accordance with Practice B 117.

11.2.2 *Humidity*—Determine the humidity resistance of coil-coated material in accordance with Practices D 2247 and D 1735. The former method generates the 100 % humidity condition by heating water in the bottom of the cabinet, while the latter method achieves the identical set of conditions by using an atomization tower (as is used in Practice B 117).

11.2.3 *Controlled Condensation*—Determine the resistance of coil-coated material to water in accordance with Practice D 4585 (also known as "Cleveland Condensing" test).

11.2.4 *Water Immersion*—Determine the resistance of a coil-coated material to water immersion in accordance with Practice D 870.

11.2.5 *Cyclic Humidity and Salt Spray*—Alternatives to a constant state of 100 % humidity are Test Methods G 60 (cyclic humidity), Practices G 85 (cyclic salt spray), and D 5894 (cyclic salt fog/UV condensation). There have been some encouraging studies that indicate that cyclic test methodology (humidity cycle, with or without electrolyte, coupled with a dry cycle) may be more predictive of real-time corrosion effects, under multiple service conditions.

11.2.6 *Moist $SO_2$ ("Kesternich")*—To assess to effect of exposure to $SO_2$, test in accordance with Practice G 87.

NOTE 3—Since the level of $SO_2$ used in this practice is considerably higher than those levels experienced anywhere in the world, the coil coating industry generally feels that Practice G 87 should be only interpreted as providing a certain level of information about the coating's resistance to change color (as a result of the pigments reacting with the $SO_2$ in air). Other events, such as blistering, are generally ignored.

11.2.7 *Copper-Accelerated Salt Spray (CASS)*—This is another test often used when aluminum substrate is involved. Test in accordance with Test Method B 368.

11.2.8 *Filiform Corrosion*—Evaluate a coil coating system's tendency to display filiform resistance in accordance with Guide D 2803.

11.2.9 *Specification for Reagent Water*—Should reagent water information be needed, test in accordance with Specification D 1193.

11.3 *Accelerated Weathering*:

11.3.1 *Accelerated Weathering*—Laboratory and outdoor tests cause faster degradation of coating films than would be the case under natural outdoor weathering conditions. Laboratory accelerated tests allow for control of exposure conditions. If, however, the exposure conditions of the accelerated test (such as the spectral power distribution (SPD), "time of wetness," and temperature) differ from those condition to which the material will be exposed in the field, the type of failure and mechanism of degradation may differ from those effects experienced in real-time outdoor exposure. Certain accelerated devices have been developed in an attempt to match the SPD of normal sunshine.

NOTE 4—"Normal" sunshine varies depending on the location on the planet, as well as the season of the year. Winter sunshine contains a considerably smaller UV component than that in the summer season. The xenon arc device, with the proper filters, matches the normal sunlight SPD quite well in the UV, visible and near-infrared (NIR) regions. Emission from fluorescent UVA-340 bulbs matches a portion of the UV spectrum of natural sunlight, but includes only a negligible amount of visible and NIR energy. UVB-313 bulbs, on the other hand, emit UV radiation below the earth's solar cut-off (295 nm), and, as a result, different degradation reactions may occur than that which would occur in normal daylight. Fresnel devices collect and concentrate "direct beam" normal sunlight, but short wavelength UV radiation is not reflected completely due to the limitations of the reflector and scattering by the earth's atmosphere so that a portion of the short wavelengths are eliminated from the sun's direct beam. In general, the optimum simulation of effects of natural exposures is obtained with a test source that accurately simulates the full spectrum of the natural source in the UV region, and through the near infrared region (250 to 3000 nm). A close match to the UV spectral power distribution of daylight reduces the possibility of different failure mechanisms and reversals in stability rankings of materials. Accelerated devices that can simulate the visible and near infrared regions of the sunlight's SPD is important when testing colored materials. Both visible and near infrared radiation- absorbed increases the temperature of the specimens, thus accelerating the secondary degradations reactions.

11.3.2 *Dew Cycle (Unfiltered Open-Flame Carbon Arc)*—Test a coating's response to dew cycle exposure in accordance with Practices D 3361 and G 151.

11.3.3 *Filtered, Open-Flame Carbon Arc Weather-Ometer*—Test in accordance with Practice D 822, G 151, and G 152.

11.3.4 *Fluorescent UV-Condensation Device*—Test in accordance with Practices D 4587, G 151, and G 154.

11.3.5 *Enclosed Carbon Arc Device*—Test in accordance with Practices D 5031, G 151, and G 153.

11.3.6 *Xenon Arc Device*—Test in accordance with Practice G 151, and G 155.

11.3.7 *Accelerated Outdoor Tests (Black Box, Heated Black Box, Fresnel Device)*—Test in accordance with Practices D 4141, G 7, and G 90.

11.4 *Measuring Solar Reflectance*:

11.4.1 *Measuring Solar Reflectance of Horizontal and Low-Slope Surfaces in the Field*—Test in accordance to Test Method E 1918.

11.4.2 *Measuring Total Normal Emittance*—Test in accordance to Test Methods E 408.

11.4.3 *Measuring Solar Absorptance, Reflectance, and Transmittance Using Integrating Spheres*—Test in accordance with Test Method E 903.

11.4.4 Tables for Spectral Irradiance at Air Mass 1.5: Direct Normal and Hemispherical for a 37° Tilted Surface.

## 12. Keywords

12.1 absorbance; accelerated; acetic acid; adhesion; chip resistance; chromate; coil coatings; color; cone and plate; cyclic; density; dew cycle; film thickness; flame spread; fluorescent-UV condensation; Fresnel; glass transition; hardness; humidity; impact; irradiance; Kesternich; metamerism; methods; pH; phosphate; reflectance; salt spray; solar reflectance; solids; solvent resistance; standards; Taber; T bends; transmittance; viscosity; VOC; weathering; xenon; Zahn