



Standard Guide for Testing Industrial Protective Coatings¹

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1. Scope

1.1 This guide covers the selection and use of test methods and procedures for testing industrial protective coatings. Selection of the standards to be followed must be governed by experience and the requirements in each individual case, together with agreement between the supplier and the user.

1.2 This guide covers the testing of liquid coatings as applied on substrate by brushing, rolling, spraying, or other means appropriate to the coating and circumstance.

NOTE 1—The term “industrial protective coating” as used in this guide is described in the scope of Subcommittee D01.46¹ as “paints applied to substrates on-site of structures and buildings, especially where subject to corrosive environments, as industrial, urban, and marine environments.”

NOTE 2—Guides for testing other coating types, such as Guides D4712, D5136, D5324 or for surface preparation, coating application, such as Guide D3276, are available and should be used when it is applicable.

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:²

- B117 Practice for Operating Salt Spray (Fog) Apparatus
- C868 Test Method for Chemical Resistance of Protective Linings (Withdrawn 2015)³
- D16 Terminology for Paint, Related Coatings, Materials, and Applications
- D56 Test Method for Flash Point by Tag Closed Cup Tester
- D93 Test Methods for Flash Point by Pensky-Martens Closed Cup Tester
- D185 Test Methods for Coarse Particles in Pigments

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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.

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

- D344 Test Method for Relative Hiding Power of Paints by the Visual Evaluation of Brushouts
- D522 Test Methods for Mandrel Bend Test of Attached Organic Coatings
- D523 Test Method for Specular Gloss
- D562 Test Method for Consistency of Paints Measuring Krebs Unit (KU) Viscosity Using a Stormer-Type Viscometer
- D609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products
- 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
- D662 Test Method for Evaluating Degree of Erosion of Exterior Paints
- D714 Test Method for Evaluating Degree of Blistering of Paints
- D772 Test Method for Evaluating Degree of Flaking (Scaling) of Exterior 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, Varnish, and Related Products on Test Panels
- D869 Test Method for Evaluating Degree of Settling of Paint
- 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
- 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
- D1296 Test Method for Odor of Volatile Solvents and Diluents

- D1308** Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes
- D1474** Test Methods for Indentation Hardness of Organic Coatings
- D1475** Test Method For Density of Liquid Coatings, Inks, and Related Products
- D1535** Practice for Specifying Color by the Munsell System
- D1640** Test Methods for Drying, Curing, or Film Formation of Organic Coatings
- D1653** Test Methods for Water Vapor Transmission of Organic Coating Films
- 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
- D1730** Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting
- D1731** Practices for Preparation of Hot-Dip Aluminum Surfaces for Painting
- D1732** Practices for Preparation of Magnesium Alloy Surfaces for Painting
- D1735** Practice for Testing Water Resistance of Coatings Using Water Fog Apparatus
- D1849** Test Method for Package Stability of Paint
- D2196** Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational Viscometer
- D2197** Test Method for Adhesion of Organic Coatings by Scrape Adhesion
- D2200** Practice for Use of Pictorial Surface Preparation Standards and Guides for Painting Steel Surfaces
- D2201** Practice for Preparation of Zinc-Coated and Zinc-Alloy-Coated Steel Panels for Testing Paint and Related Coating Products
- D2243** Test Method for Freeze-Thaw Resistance of Water-Borne Coatings
- 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
- D2354** Test Method for Minimum Film Formation Temperature (MFFT) of Emulsion Vehicles
- D2369** Test Method for Volatile Content of Coatings
- D2371** Test Method for Pigment Content of Solvent-Reducible Paints
- D2574** Test Method for Resistance of Emulsion Paints in the Container to Attack by Microorganisms
- D2616** Test Method for Evaluation of Visual Color Difference With a Gray Scale
- D2621** Test Method for Infrared Identification of Vehicle Solids From Solvent-Reducible Paints
- 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
- D2805** Test Method for Hiding Power of Paints by Reflectometry
- D2832** Guide for Determining Volatile and Nonvolatile Content of Paint and Related Coatings
- D3134** Practice for Establishing Color and Gloss Tolerances
- D3168** Practice for Qualitative Identification of Polymers in Emulsion Paints
- D3170** Test Method for Chipping Resistance of Coatings
- D3276** Guide for Painting Inspectors (Metal Substrates)
- D3278** Test Methods for Flash Point of Liquids by Small-Scale Closed-Cup Apparatus
- D3359** Test Methods for Measuring Adhesion by Tape Test
- D3363** Test Method for Film Hardness by Pencil Test
- D3792** Test Method for Water Content of Coatings by Direct Injection Into a Gas Chromatograph
- D3793** Test Method for Low-Temperature Coalescence of Latex Paint Films by Porosity Measurement (Withdrawn 2012)³
- D3912** Test Method for Chemical Resistance of Coatings and Linings for Use in Nuclear Power Plants
- D3924** Specification for Environment for Conditioning and Testing Paint, Varnish, Lacquer, and Related Materials
- D3925** Practice for Sampling Liquid Paints and Related Pigmented Coatings
- D3928** Test Method for Evaluation of Gloss or Sheen Uniformity
- D3960** Practice for Determining Volatile Organic Compound (VOC) Content of Paints and Related Coatings
- D4017** Test Method for Water in Paints and Paint Materials by Karl Fischer Method
- D4060** Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
- D4062** Test Method for Leveling of Paints by Draw-Down Method
- 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
- 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
- D4400** Test Method for Sag Resistance of Paints Using a Multinotch Applicator
- D4457** Test Method for Determination of Dichloromethane and 1,1,1-Trichloroethane in Paints and Coatings by Direct Injection into a Gas Chromatograph
- D4541** Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers
- D4585** Practice for Testing Water Resistance of Coatings Using Controlled Condensation
- D4587** Practice for Fluorescent UV-Condensation Exposures of Paint and Related Coatings
- D4712** Guide for Testing Industrial Water-Reducible Coatings (Withdrawn 2014)³

- D4752 Practice for Measuring MEK Resistance of Ethyl Silicate (Inorganic) Zinc-Rich Primers by Solvent Rub
- D4958 Test Method for Comparison of the Brush Drag of Latex Paints
- D5009 Test Method for Evaluating and Comparing Transfer Efficiency of Spray Applied Coatings Under Laboratory Conditions
- D5031 Practice for Enclosed Carbon-Arc Exposure Tests of Paint and Related Coatings
- D5064 Practice for Conducting a Patch Test to Assess Coating Compatibility
- D5065 Guide for Assessing the Condition of Aged Coatings on Steel Surfaces
- D5146 Guide to Testing Solvent-Borne Architectural Coatings
- D5162 Practice for Discontinuity (Holiday) Testing of Nonconductive Protective Coating on Metallic Substrates
- D5178 Test Method for Mar Resistance of Organic Coatings
- D5201 Practice for Calculating Formulation Physical Constants of Paints and Coatings
- D5286 Test Methods for Determination of Transfer Efficiency Under General Production Conditions for Spray Application of Paints
- D5324 Guide for Testing Water-Borne Architectural Coatings
- D5327 Practice for Evaluating and Comparing Transfer Efficiency of Spray Applied Coatings Under General Laboratory Conditions
- D5402 Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs
- D5894 Practice for Cyclic Salt Fog/UV Exposure of Painted Metal. (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)
- D5895 Test Methods for Evaluating Drying or Curing During Film Formation of Organic Coatings Using Mechanical Recorders
- D6093 Test Method for Percent Volume Nonvolatile Matter in Clear or Pigmented Coatings Using a Helium Gas Pycnometer
- D6132 Test Method for Nondestructive Measurement of Dry Film Thickness of Applied Organic Coatings Using an Ultrasonic Coating Thickness Gage
- D6578 Practice for Determination of Graffiti Resistance
- D6677 Test Method for Evaluating Adhesion by Knife
- D6695 Practice for Xenon-Arc Exposures of Paint and Related Coatings
- D6905 Test Method for Impact Flexibility of Organic Coatings
- D6943 Practice for Immersion Testing of Industrial Protective Coatings and Linings
- D6944 Practice for Determining the Resistance of Cured Coatings to Thermal Cycling
- D7055 Practice for Preparation (by Abrasive Blast Cleaning) of Hot-Rolled Carbon Steel Panels for Testing of Coatings
- 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
- D7187 Test Method for Measuring Mechanistic Aspects of Scratch/Mar Behavior of Paint Coatings by Nanoscratching
- D7868 Practice for Determining the Dry Fall (Fog) Properties of Protective Coatings
- E84 Test Method for Surface Burning Characteristics of Building Materials
- F1249 Test Method for Water Vapor Transmission Rate Through Plastic Film and Sheeting Using a Modulated Infrared Sensor
- G7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
- G8 Test Methods for Cathodic Disbonding of Pipeline Coatings
- G14 Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test)
- G20 Test Method for Chemical Resistance of Pipeline Coatings
- G42 Test Method for Cathodic Disbonding of Pipeline Coatings Subjected to Elevated Temperatures
- G50 Practice for Conducting Atmospheric Corrosion Tests on Metals
- G62 Test Methods for Holiday Detection in Pipeline Coatings
- G80 Test Method for Specific Cathodic Disbonding of Pipeline Coatings (Withdrawn 2013)³
- G85 Practice for Modified Salt Spray (Fog) Testing
- G90 Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight
- G95 Test Method for Cathodic Disbondment Test of Pipeline Coatings (Attached Cell Method)
- G106 Practice for Verification of Algorithm and Equipment for Electrochemical Impedance Measurements
- G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials
- G141 Guide for Addressing Variability in Exposure Testing of Nonmetallic Materials
- G147 Practice for Conditioning and Handling of Nonmetallic Materials for Natural and Artificial Weathering Tests
- 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 Light Apparatus for Exposure of Non-Metallic Materials
- 2.2 *Federal Standards:*⁴
- U.S. Federal Test Method Standard No. 141C:
- 1022 Sampling for Inspection and Testing
- 2112 Application by Roller
- 2131 Application of Sprayed Films

⁴ Available from DLA Document Services, Building 4/D, 700 Robbins Ave., Philadelphia, PA 19111-5094, <http://quicksearch.dla.mil>.

- 2141 Application of Brushed Films
- 2161 Application of Film with Film Applicator (Magnetic Chuck)
- 2162 Application of Film with Film Applicator Using Suction Panel Holder
- 3011 Condition in Container
- 4061 Drying Time
- 4321 Brushing Properties
- 4331 Spraying Properties
- 4335 Roller Coating Properties
- 4401 Odor Test
- 2.3 *U.S. Environmental Protection Agency Standard*:⁵
- EPA Federal Reference Method 24** Determination of Volatile Matter Content, Density, Volume Solids, and Weight Solids of Surface Coatings
- 2.4 *NACE Standard*:⁶
- NACE TM0174** Laboratory Methods for the Evaluation of Protective Coatings and Lining Materials in Immersion Service
- 2.5 *ANSI Standard*:⁷
- N512** Protective Coatings (Paints) for the Nuclear Industry

3. Terminology

3.1 Definitions:

3.1.1 For definitions of terms used in this guide, refer to Terminology **D16**.

3.1.2 The definitions given in Terminology **G113** relating to natural and artificial weathering tests are applicable to this guide.

4. Significance and Use

4.1 This guide is intended to provide assistance in selecting appropriate tests for evaluating the general performance level to be expected of a coating or coating system on a given substrate exposed to a given type of environment. **Table 1** represents a listing of all the tests.

4.2 Surface preparation or cleanliness prior to application of the coating can be critical to the proper performance of the coating.

4.3 Results obtained in the tests cited in this guide may not be adequate for predicting coating service life of a specific coating system in a specific environmental exposure. A suitable control coating system of known performance in the service environment should be included in the testing for comparison.

5. Conditions Affecting Performance

5.1 Practical requirements and performance of industrial coatings may vary with the following:

5.1.1 *Substrate Type*—Ferrous, nonferrous, previously coated surfaces, masonry, and other materials.

⁵ Available from U.S. Government Printing Office Superintendent of Documents, 732 N. Capitol St., NW, Mail Stop: SDE, Washington, DC 20401, <http://www.access.gpo.gov>.

⁶ Available from NACE International (NACE), 1440 South Creek Dr., Houston, TX 77084-4906, <http://www.nace.org>.

⁷ Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, <http://www.ansi.org>.

5.1.2 *Substrate Conditions and Surface Profile*—Cleanliness, porosity, smoothness, and weathering of the substrates.

5.1.3 *Substrate Aspects of Structure*—Construction defects or defects due to age such that excessive moisture makes its way through a porous substrate or is trapped in components; design defects that cause galvanic corrosion; environmental exposure to deteriorating materials such as deicing salts, improperly prepared welds, or other site-specific detrimental conditions.

5.1.4 Type, quality, and suitability of the surface treatment or primer used and time of drying before coating application.

5.1.5 Application methods and techniques.

5.1.6 *Application and Cure Conditions*—Environmental conditions, such as temperature and relative humidity, during application and drying.

5.1.7 *Service Conditions*—Environmental conditions such as solar radiation, temperature, humidity, and chemical and mechanical stress.

6. Sampling and Test Conditions

6.1 Prior to sampling, the condition of the container should be checked since damage to it may cause evaporation, skinning, or other undesirable effects on the coating.

6.2 Sample in accordance with Practice **D3925** or Method 1022 of Federal Test Method Standard No. 141C. Prepare coating films of uniform thickness on test panels in accordance with Practices **D823**.

6.3 Tests and observations shall be at standard laboratory conditions in accordance with Specification **D3924** unless otherwise specified or agreed upon between the supplier and the user.

7. Liquid Coatings Properties

7.1 *Condition in Container*—Thickening, settling, and separation are undesirable and objectionable if a liquid coating cannot be reconditioned and made suitable for application with a reasonable amount of stirring. The referenced test method, Method 3011.1 covers procedures for determining changes in properties after storage. Determine the condition in the container in accordance with Method 3011.1 of U.S. Federal Test Method Standard No. 141C.

7.2 *Coarse Particles and Foreign Matter*—Liquid coatings must be free of coarse particles and foreign matter to be able to form uniform films of good appearance. A typical maximum value is 0.5 weight % of the total material. Determine the content of coarse particles and foreign matter in accordance with Test Methods **D185**. This referenced method uses material retained in a 325-mesh (45- μ m) screen as a measure of coarse particle and foreign matter.

7.3 *Density or Weight per Gallon*—The density as measured by weight per gallon is used to help ensure product uniformity from batch to batch. Test Method **D1475** gives a procedure for measuring the density of the coating at specified temperature. A calibrated weight-per-gallon cup is used. Determine the density in accordance with Test Method **D1475**.

TABLE 1 List of Test Methods by Properties

Property or Related Test	Section	ASTM Standard	Federal Test Method Standard No. 141C
Scope:			
Guides	1.2	D3276, D4712, D5146, D5324	...
Terminology	3.1.1	D16	...
	3.1.2	G113	...
Sampling and Test Conditions:			
Sampling	6.2	D823, D3925	1022
Test conditions	6.3	D3924	...
Liquid Coatings Properties:			
Condition in container	7.1	...	3011
Coarse particles and foreign matter	7.2	D185	...
Density or weight per gallon	7.3	D1475	...
Fineness of dispersion	7.4	D1210	...
Settling	7.5	D869	...
Viscosity:	7.6		
Newtonian fluids	7.6.1	D1200, D2196, D4212	...
Consistency	7.6.2	D562	...
High-shear viscosity	7.6.3	D4287, D4958	...
Flash point	7.7	D56, D93, D3278	...
Freeze-thaw stability	7.8	D2243	...
Odor	7.9	D1296	4401
Microorganism resistance	7.10	D2574	...
Package stability	7.11	D1849	...
Volatile content of coatings	7.12	D2369, D2832	...
Volume solids	7.13	D2697, D5201, D6093	...
Volatile organic content	7.14	D1475, D2369, D3792, D3960, D4017, D4457	...
Chemical analysis	7.15	D2371, D2621, D3168	...
Transfer efficiency	7.16	D5009, D5286, D5327	...
Application and Film Formation:			
Panel preparation	8		
Panel preparation	8.1	D609, D1730, D1731, D2200, D7055	...
Application properties	8.2	D7868	2112, 2131, 2141, 2161, 2162, 4321, 4331, 4335, 4061
Drying properties	8.3	D1640, D5895	...
Leveling properties	8.4	D4062	...
Wet film thickness	8.5	D1212	...
Low temperature coalescence of paints	8.6	D2354, D3793	...
Touch-up	8.7	D3359, D3928	...
Sag resistance	8.8	D4400	...
Pot life	8.9
Appearance of Dry Film:			
Color:	9		
Color difference by visual evaluation	9.1		
Color difference by instrumental evaluation	9.1.1	D1729, D2616	...
Color difference by instrumental evaluation	9.1.2	D2244, D3134	...
Color description by visual evaluation	9.1.3	D1535	...
Color description by instrumental evaluation	9.1.4	D2244	...
Gloss	9.2	D523, D3134	...
Hiding power	9.3	D344, D2805	...
Properties of Dry Film:	10		
Abrasion resistance	10.1	D968, D4060	...
Adhesion	10.2	D2197, D3359, D4541	...
Dry film thickness	10.3	D1005, D4138, D6132, D7091	...
Elongation	10.4	D522	...
Internal stresses	10.5
Hardness	10.6	D1474, D3363, D5178, D7187	...
Discontinuity (Holiday)	10.7	D5162, G62	...
Impact resistance	10.8	D2794, D3170, D6905, G14	...
Burning characteristics	10.9	E84	...
Slip coefficient and creep resistance	10.10
Performance of Dry Film:	11		
Moisture vapor transmission rate	11.1	D1653, F1249	...
Cathodic disbonding	11.2	G8, G42, G80, G85	...
Chemical resistance	11.3	C868, D1308, D3912, D4752, D5402, G20, G106	...
Moisture resistance	11.4	D870, D1735, D2247, D4585	...
Exterior exposure:	11.5		
Conducting	11.5.1	D1014, G50	...
Atmospheric exposure	11.5.2	G7	...
Accelerated outdoor weathering	11.5.3	D4141, G90	...
Patch test	11.5.4	D5064	...
Laboratory exposure:	11.6		
Accelerated weathering	11.6.1	G141, G147, G151	...
Enclosed carbon arc	11.6.1.1	D5031, G153	...
Open flame carbon arc	11.6.1.2	D822, G152	...

TABLE 1 *Continued*

Property or Related Test	Section	ASTM Standard	Federal Test Method Standard No. 141C
Xenon arc	11.6.1.3	D6695, G155	...
Fluorescent UV	11.6.1.4	D4587, G154	...
Corrosion resistance:	11.6.2	B117, D5894, G85	...
Cyclic wet/dry test (Prohesion)	11.6.2.1	G85	...
Cyclic corrosion/UV	11.6.2.2	D5894	...
Salt for (spray)	11.6.2.3	B117, G85	...
Filiform corrosion	11.6.2.4	D2803	...
Report results	11.7	D610, D660, D661, D662, D714, D772, D1654, D4214, D5065	...

7.4 Fineness of Dispersion—Pigmented paints involve the dispersion of colored pigments and filler pigments into the liquid vehicle. Generally, the more finely a pigment is dispersed, the more efficiently it is being utilized. The fineness of dispersion (or fineness of “grind”) provides a means to measure and report the degree to which pigment agglomerates have been broken down in the dispersion process. The degree of dispersion can affect paint properties such as color, gloss, and pigment settling. Determine fineness of dispersion in accordance with Test Method **D1210**.

7.5 Settling—The amount and type of settling is an indication of how well the pigments remain in suspension and how easily settled pigment can be remixed. Pigments and fillers dispersed in paints are subject to settling as generally described in Stokes Law. Determine the degree of settling in accordance with Test Method **D869**.

7.6 Viscosity—Viscosity refers to the flow resistance of a fluid. Viscosity values are often related to application properties such as flow, leveling, and sag resistance and should fall within an agreed-upon range.

7.6.1 Viscosity of Newtonian or Near Newtonian Fluids (constant viscosity regardless of shear rate), may be measured in accordance with Test Methods **D1200** and **D4212**. This viscosity measurement is used to determine package viscosity and application viscosity. Viscosity of non-Newtonian materials should be measured in accordance with Test Methods **D2196** since it measures resistance to flow at different shear rates. The ratio of viscosity values at different shear rates is also a way of measuring thixotropy often related to film build or sag resistance. Determine viscosity in accordance with Test Methods **D1200** or **D2196**.

7.6.2 Consistency (Low-Shear Viscosity)—Consistency is used mainly to ensure product uniformity. Consistency is defined in Test Method **D562** as the load in grams required to produce a specific rate of rotation in a specimen using the Stormer viscometer. This is a one-speed test method. Two paints of the same consistency may have quite different rheological properties during application. Determine consistency in accordance with Test Method **D562**.

7.6.3 High-Shear Viscosity—The viscosity of a paint under high shear is related to its behavior when brushed, rolled, or sprayed. In Test Methods **D4287** and **D4958**, the shear rate is similar to that occurring during brush application so that the measured viscosity is related to brush drag, spreading rate, and film build. High-shear viscosity is more likely used in the development and quality control of paints than a requirement in

a paint specification. Determine high-shear viscosity in accordance with Test Method **D4287**.

7.7 Flash Point—Flash point refers to the lowest temperature at which a vapor will ignite if presented with an ignition source such as a flame or spark. The flash point for a paint is needed to conform with many government regulations concerning transportation, labeling, packaging, and storage procedures. Determine flash point in accordance with Test Methods **D56**, **D93**, or **D3278**.

7.8 Freeze-Thaw Stability—Waterborne coatings may be subjected to freezing conditions during shipping and storage. Suitably stabilized products can resist several cycles of freezing and thawing without showing deleterious changes such as coagulation, graininess (seeding), or excessive viscosity increase. Test Method **D2243** covers the determination of the extent to which waterborne coatings retain their original consistency and freedom from lumps when subjected to freezing and subsequent thawing. Determine freeze-thaw resistance in accordance with Test Method **D2243**.

7.9 Odor—Odor is often associated with the volatile components: organic solvents or ammonia in waterborne coatings. No specific ASTM test method is available for evaluating odor. Method 4401 of Federal Test Method Standard No. J41C does address “characteristic” or expected odor. Test Method **D1296** may also be suitable as the basis for a test even though it is not specifically designed for liquid coatings.

7.10 Microorganism Resistance—Microorganisms in waterborne paints can cause gassing, putrefaction, or fermentation and their corresponding odors, and loss in viscosity and film build capability. Determine if the liquid coating contains living bacteria and if it is resistant to attack by bacteria in accordance with Test Method **D2574**.

7.11 Package Stability—Since liquid coatings cannot normally be used immediately after manufacture, they must remain stable in the package for some time. Test Method **D1849** covers the change in consistency and in certain related properties that may take place in packaged coatings when stored at a temperature above room temperature. Determine package stability in accordance with Test Method **D1849**.

7.12 Volatile Content of Coatings—Test Method **D2369** is used to determine the weight percent volatile content of coatings. Test Method **D2369** is also used in the determination of the volatile organic compound (VOC) content of coatings (Practice **D3960** and EPA Method 24). Test Method **D2369** can

also be used to set acceptance limits in qualification testing or purchase specifications. Guide **D2832** provides a guideline in selecting standards for determining volatile and nonvolatile content of paint.

7.13 Volume Solids Content—The volume of solid materials from a can of paint is related to the spread rate at recommended dry film thickness and 100 % transfer efficiency. The volume of solid materials can be used to calculate the number of square feet a gallon of paint will cover at recommended film thickness and actual transfer efficiency. The volume solids value then can be used to estimate the amount of paint needed for a job or allow a common basis for the economic comparison of competitive paints whose volume solids and recommended film thickness may differ. The measured value of volume solids may not equal volume solids based on calculation (Practice **D5201**). Determine volume solids in accordance with Test Methods **D2697** and **D6093**.

7.14 Volatile Organic Compound Content—The U.S. EPA Federal Reference Method 24 is the regulatory method of VOC content determination. Practice **D3960** is used to determine the VOC content of the paint, based on volatile content, Test Method **D2369**, density, Test Method **D1475**, water content, Test Method **D3792** (GC analysis) or Test Method **D4017** (Karl Fischer titration), and exempt solvent, Test Method **D4457** (GC analysis for 1,1,1-trichloroethane).

7.15 Chemical Analysis—Chemical analysis determines the presence of specified components and their quantities. Test Method **D2621** and Practice **D3168** address the use of infrared spectroscopy to identify paint vehicle solids. Test Method **D2371** describes the procedure for quantitative separation of the vehicle from the pigment in coatings to determine the weight percent pigment in the paint. More complete series of test methods by which paint or its component materials may be analyzed, are governed by Subcommittee D01.21.

7.16 Transfer Efficiency—The transfer efficiency of paint is defined as the ratio of paint solids deposited to the total paint solids used during the application process, expressed as a percent. Transfer efficiency is important in qualifying application test methods in certain regulated regions of the country. Transfer efficiency is a function of the application test method, application equipment, and operator skill. Determine transfer efficiency of a coating application test method or equipment in accordance with Test Methods **D5009** and **D5286** and Practice **D5327**.

8. Application and Film Formation

8.1 Panel Preparation—Select a substrate as agreed upon between the supplier and the user. Prepare panels in accordance with appropriate Practices **D609**, **D1730**, **D1731**, **D1732**, **D2200**, **D2201**, or **D7055**.

8.2 Application Properties—Determine the ease with which the liquid coating can be applied to various surfaces with brush, spray, or other application equipment. Application properties are generally compared to a standard, or described by requirements in a product specification. Application properties are related to such characteristics as kinetic viscosity, non-Newtonian rheology, surface tension, shear sensitivity,

micelle stability, electrical resistivity, erosion abrasiveness, conductivity, heat capacity, corrosiveness, and dry fall capabilities (in accordance with Practice **D7868**). Determine the application properties in accordance with Method 2112, 2131, 2141, 2161, 2162, 4321, 4331, or 4335 of Federal Test Method Standard No. 141C.

8.3 Drying Properties—The drying time of the coatings is important in determining when the applied coatings can be handled or packed. Also, inadequate drying of the film may result in poor film and poor appearance and if used on an exterior surface, rain, dew, or snow may cause a nonuniform appearance. Determine drying time in accordance with Test Methods **D1640**, **D5895**, Method 4061 of the Federal Test Method Standard No. 141C, or as agreed upon between the purchaser and the seller.

8.4 Leveling Properties—Leveling is an important factor when uniform surfaces are to be produced, as it affects hiding and appearance. The referenced test method covers the laboratory determination of the relative leveling characteristics of liquid coatings. Determine the leveling characteristics in accordance with Test Method **D4062**.

8.5 Wet Film Thickness—The measurement of wet film thickness provides opportunity to check the coating and its application process. It is important that wet film measurements are made as soon as the coating is applied to avoid error due to solvent loss during the curing process. Determine the wet film thickness in accordance with Test Methods **D1212**.

8.6 Low-Temperature Coalescence of Paints—A test method to determine how well the latex particles in coating will fuse together or coalesce to form a continuous film at low temperature is described in Test Method **D3793**. A test for the minimum film formation temperature is described in Test Method **D2354**.

8.7 Touch-Up—For many coating systems it is important to be able to repair damage sustained during production, delivery, or after delivery. A coating can be tested by applying it with a small nylon bristle brush or air brush to a small section of a panel previously coated with it. When the touch-up area has dried, it is examined to see if its appearance is significantly different than the appearance of the initial coating. Determine the ability to touch up the coating in accordance with Test Method **D3928**. Test the adhesion of the original and touch-up areas in accordance with Test Methods **D3359** or other agreed upon test method.

8.8 Sag Resistance—Sagging is driven by gravitational shear stress. The sagging shear stress magnitude depends entirely on the wet film thickness and density. Test the sag resistance in accordance with Test Methods **D4400**.

8.9 Pot Life—Pot life is the length of time in which the application and performance properties of catalyzed paints will not change within an acceptable range. Pot life of the coating can be determined by monitoring the change in coating application and performance properties over time using various viscosity, sag resistance, application, and performance tests.

9. Appearance of Dry Film

9.1 *Color*—The color of the coating may be specified independently or as the color-difference with respect to another color that is usually the standard. Visual and instrumental methods are both applicable. An opaque film may be prepared by making one or more applications of coating onto a black-and-white substrate until the substrate is completely obscured. Each application should be performed in a normal manner with respect to application method, drying, and film thickness.

9.1.1 *Color Differences by Visual Evaluation*—Visual comparison of color is fast, and often acceptable, although numerical values are not obtained. Practice D1729 covers the spectral, photometric, and geometric characteristics of light source, illuminating and viewing conditions, size of specimens, and general procedures to be used in the visual evaluation of color differences of opaque materials. Determine color difference by visual evaluation in accordance with Practice D1729 or Test Method D2616.

9.1.2 *Color Differences of Opaque Material by Instrumental Evaluation*—Instruments can measure color difference between a product and the standard. Generally, the tolerance is agreed upon between the supplier and the user and may also be required if a product specification is involved. Color measuring instruments provide numerical values that can be subsequently compared to later measurements. Practice D2244 covers the instrumental determination of small color differences observable under daylight illumination between nonfluorescent, nonmetameric, opaque surfaces such as coated specimen. If metamerism is suspected, visual evaluation (9.1.1) should be used to verify the results. Make instrumental measurement of color difference in accordance with Practice D2244. Tolerances are discussed in Practice D3134.

9.1.3 *Color Description by Visual Evaluation*—In some cases, it is necessary to specify or identify a color instead of a color difference from some standard. Various color atlases are available, the most common being the Munsell System. Describe or identify the Munsell color in accordance with Practice D1535.

9.1.4 *Color Description by Instrumental Evaluation*—Instrumental measurements involve the determination of CIE tristimulus values, X , Y , and Z , from which other color coordinates such as L^* , a^* , b^* or L , a , b values may be calculated or obtained directly with some instruments. Describe or identify in accordance with Practice D2244.

9.2 *Gloss*—The end use determines whether the gloss should be high, semigloss, eggshell, or flat. Determine the gloss in accordance with Test Method D523 using 20, 60, or 85 geometry as appropriate. Determine the gloss tolerances in accordance with Practice D3134.

9.3 *Hiding Power (Dry Opacity)*—Hiding power is the measure of the ability of a paint to hide the substrate. Test Method D344 is a practical test in which paint is applied with a brush, film thickness is approximately measured, and opacity is evaluated visually as compared to a standard paint. Results are affected by flow and leveling application properties of the

paint. Test Method D2805 is considered to be a more precise and accurate test method that does not need a material paint standard. Paint is applied with an applicator bar to minimize the effects of flow and leveling, film thickness is rigorously measured, and opacity is instrumentally evaluated. Determine hiding power in accordance with Test Methods D344 or D2805.

10. Properties of Dry Film

10.1 *Abrasion Resistance*—Abrasion resistance is a measure of the ability of a dried coating to withstand wearing by frictional movements of another solid, liquid, or gas, or combination thereof. Coatings can be damaged by abrasion during manufacturing and service. Determine abrasion resistance in accordance with Test Methods D968 or D4060.

10.2 *Adhesion*—Adhesion is the property of the coating that resists removal from the substrate. Test Method D2197 covers the use of a scrape adhesion tester and a parallel groove adhesion tester. In Test Methods D3359, cuts are made in the film and pressure-sensitive tape applied and removed. The pull-off test, Test Method D4541, is a measurement of tensile stress as compared to the shear stress measurements applied by other scratch adhesion methods. The pull adhesion testers are portable and capable of applying a concentric load and counter load to a single surface. The pull-off strength is computed based on the maximum indicated load, the instrument calibration data, and the original surface area stressed. Determine knife adhesion in accordance with Test Method D6677.

10.2.1 *Thermal Cycling*—Thermal stress can affect adhesion and other properties of coatings. Test Method D6944 helps assess the influence of thermal cycling but is not intended as a quantitative assessment of service life on a specific cured coating. There are two methods used to test a cured test specimen. Method A consists of 30 thermal cycles of immersion, freezing and heating and Method B is 30 cycles of freezing and heating.

10.3 *Dry Film Thickness*—There are several test methods currently being used for determining dry film thickness. Depending on the substrates being used, the following test methods should be considered: Test Methods D1005, D4138, D6132, and D7091.

10.4 *Elongation*—Elongation is the increase in the length of a dried and cured coating as a result of tensile stress, usually expressed as a percentage of the original length. Elongation is a measure of the coating flexibility and its ability to withstand the deformation of supporting surfaces without cracking or peeling. Determine elongation in accordance with Test Methods D522.

10.5 *Internal Stresses*—Internal stresses in coatings arise as a result of their shrinkage, expansion, cross-linking, or differences in thermal expansion coefficients between coating and substrate, which may lead to cracking or loss of adhesion. Internal stresses may be determined quantitatively by strain gauge or the cantilever methods that measure the curvature

(deflection) of one-side coated panels, which will curve or bend due to forces exerted at the substrate-coating interface as a result of internal stresses.^{8,9}

10.6 Hardness—Hardness is a measure of the ability of dried coating to resist indentation. Determine hardness in accordance with Test Methods **D1474**, **D3363**, **D5178** and **D7187**.

10.7 Discontinuity (Holiday)—Discontinuities such as voids, cracks, thin spots, foreign inclusions, or contamination in the coating film can significantly decrease the performance of the coating film. Discontinuities in a coating are frequently very minute and not readily visible. Practice **D5162** provides a procedure for electrical detection of minute discontinuities in nonconductive coating systems and Test Methods **G62** provides a procedure for pipeline coatings.

10.8 Impact Resistance—Impact resistance is a measure of the ability of a dried coating to withstand a striking blow or impingement. Determine the impact resistance in accordance with Test Methods **D2794**, **D3170**, **D6905**, or **G14**.

10.9 Burning Characteristics—The rate of response and the extent of degradation when organic coatings are exposed to fire depend on coating composition, temperature, and length of exposure. Determine surface burning characteristics of coating materials in accordance with Test Method **E84**.

10.10 Slip Coefficient and Creep Resistance—In steel construction, the coating used on the faying surfaces of slip-critical, high-strength, bolted connections must meet certain requirements. Specification for structural joints requires a minimum slip coefficient. The testing specification also ensures that the creep deformation of the coating due to both the clamping force of the bolt and the service load joint shear are such that the coating will provide satisfactory mechanical performance under sustained loading. Determine slip coefficient and creep resistance in accordance with American Institute of Steel Construction specification for structural joints¹⁰ or equivalent test procedures.

11. Performance of Dry Film

11.1 Moisture Vapor Transmission Rate—The capability of resisting or aiding the passage of water vapor is one of the factors affecting the performance provided by an organic coating. The water vapor transmission is not a linear function of film thickness, temperature, or relative humidity. Values of water vapor transmission rate (WVT) and water vapor permeance (WVP) can be used in the relative rating of coatings only if the coatings are tested under the same closely controlled conditions of temperature and relative humidity, and the equal film thickness. Determine water vapor transmission rate in accordance with Test Methods **D1653** and **F1249**.

⁸ Korobov, Y., and Salem, L., "Stress Analysis as a Tool in Coating Research," *Materials Performance*, Vol 29, No. 4, 1990, pp. 30-35.

⁹ Perera, D.Y., and Vander Eynde, D., "Considerations on a Cantilever (Beam) Method for Measuring the Internal Stress in Organic Coatings," *Journal of Coatings Technology*, Vol 53, No. 677, June 1981.

¹⁰ American Institute of Steel Construction, "Testing Method to Determine the Slip Coefficient for Coatings Used in Bolted Joints," *Engineering Journal*, Third Quarter, 1985, Appendix A.

11.2 Cathodic Dishbonding—Normal soil potentials as well as applied cathodic protection potentials may cause loosening of the coating, often beginning at holiday edges. An accelerated test method provides conditions for loosening to occur and therefore gives a measure of resistance of coatings to this type of action. Determine comparative characteristics of insulating coating systems applied to steel pipe exterior for the purpose of preventing or mitigating corrosion that may occur in underground service in accordance with Test Methods **G8**, **G42**, **G80**, or **G95**.

11.3 Chemical Resistance—Chemical deterioration or staining resistance test methods of coatings are to be representative of actual exposure conditions. Test Method **D1308** describes techniques for exposing the coating surface to a spot of the reagent on the coating surface. Test Methods **C868**, **D1308**, **D3912**, **G20**, Practice **D6943**, ANSI N512 Section 5 and NACE TM0174, Procedure B, Two-Side Testing, describes techniques for immersion of a coated test panel in the reagent for a specified period with timed check points. The choice of testing reagents should be related to the coatings end use. Test Method **D4752** and Practice **D5402**, MEK resistance by solvent rub, provides a quick relative test without having to wait for exposure results. This test has been shown to correlate well with the cure of some coatings tested. If the effect of a temperature gradient is to be included in the evaluation of a protective lining applied to a steel substrate, a test method which closely approximates the service conditions, including the temperature differential between the external and internal surfaces, should be used. Evaluate the chemical resistance of coating system with temperature gradient in accordance with Practice **D6943** or an alternative method NACE TM0174, Procedure A, One-Side Testing. Electrochemical impedance spectroscopy can be used to measure the coatings corrosion protection properties before and after testing when run in accordance with Practice **G106**.

11.4 Moisture Resistance—For moisture resistance tests, an environment that replicates the wet conditions of the service environment is typically preferred. If the coating is exposed to some type of water spray, Practice **D1735**, which uses a water fog apparatus should be considered. For coatings in a humid environment, Practice **D2247** is preferred. If a coating is exposed to outdoor or condensing humidity environments, Practice **D4585**, which cycles between wet and dry environments is preferred. Practice **D870** describes testing water resistance of coatings and using water immersion. Most of these tests are conducted at the anticipated temperature range of the operating environment. When accelerated test conditions are used, they should be recorded as such.

11.5 Exterior Exposure Tests—Exterior exposure testing represents a pragmatic and cost-effective approach for testing the performance of materials. Exterior exposure testing provides the ability for direct exposure to the natural, real-world environment of interest, without the need for any "weathering" simulations. An important attribute of this approach is also the fact that long-term exposure data can generally be obtained at relatively low cost. Exterior exposure data also represents a benchmark for "calibrating" the performance of accelerated laboratory tests. Exterior exposure tests have been used for