Designation: D3794 – 17

# Standard Guide for Testing Coil Coatings[1]

This standard is issued under the fixed designation D3794; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

## 1. Scope

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

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

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Some specific hazards statements are given in Section 7 on Hazards.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

B117 Practice for Operating Salt Spray (Fog) Apparatus
B368 Test Method for Copper-Accelerated Acetic Acid-Salt Spray (Fog) Testing (CASS Test)
C1371 Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers
C1549 Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer
D522 Test Methods for Mandrel Bend Test of Attached Organic Coatings
D523 Test Method for Specular Gloss
D610 Practice for Evaluating Degree of Rusting on Painted Steel Surfaces
D660 Test Method for Evaluating Degree of Checking of Exterior Paints
D661 Test Method for Evaluating Degree of Cracking of Exterior Paints
D714 Test Method for Evaluating Degree of Blistering of Paints
D822 Practice for Filtered Open-Flame Carbon-Arc Exposures of Paint and Related Coatings
D823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels
D870 Practice for Testing Water Resistance of Coatings Using Water Immersion
D968 Test Methods for Abrasion Resistance of Organic Coatings by Falling Abrasive
D1005 Test Method for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers
D1014 Practice for Conducting Exterior Exposure Tests of Paints and Coatings on Metal Substrates
D1193 Specification for Reagent Water
D1200 Test Method for Viscosity by Ford Viscosity Cup
D1210 Test Method for Fineness of Dispersion of Pigment-Vehicle Systems by Hegman-Type Gage
D1212 Test Methods for Measurement of Wet Film Thickness of Organic Coatings
D1308 Test Method for Effect of Household Chemicals on Clear and Pigmented Organic Finishes
D1474 Test Methods for Indentation Hardness of Organic Coatings
D1475 Test Method For Density of Liquid Coatings, Inks, and Related Products
D1654 Test Method for Evaluation of Painted or Coated Specimens Subjected to Corrosive Environments
D1729 Practice for Visual Appraisal of Colors and Color Differences of Diffusely-Illuminated Opaque Materials
D1735 Practice for Testing Water Resistance of Coatings Using Water Fog Apparatus
D1823 Test Method for Apparent Viscosity of Plastisols and Organosols at High Shear Rates by Extrusion Viscometer
D1824 Test Method for Apparent Viscosity of Plastisols and Organosols at Low Shear Rates

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

Current edition approved Feb. 1, 2017. Published February 2017. Originally approved in 1979. Last previous edition approved in 2016 as D3794 – 16. DOI: 10.1520/D3794-17.

[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.

D2092 Guide for Preparation of Zinc-Coated (Galvanized) Steel Surfaces for Painting (Withdrawn 2008)[3]
D2196 Test Methods for Rheological Properties of Non-Newtonian Materials by Rotational Viscometer
D2197 Test Method for Adhesion of Organic Coatings by Scrape Adhesion
D2244 Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates
D2247 Practice for Testing Water Resistance of Coatings in 100 % Relative Humidity
D2248 Practice for Detergent Resistance of Organic Finishes
D2369 Test Method for Volatile Content of Coatings
D2454 Practice for Determining the Effect of Overbaking on Organic Coatings
D2697 Test Method for Volume Nonvolatile Matter in Clear or Pigmented Coatings
D2794 Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)
D2803 Guide for Testing Filiform Corrosion Resistance of Organic Coatings on Metal
D3003 Test Method for Pressure Mottling and Blocking Resistance of Organic Coatings on Metal Substrates
D3134 Practice for Establishing Color and Gloss Tolerances
D3170 Test Method for Chipping Resistance of Coatings
D3278 Test Methods for Flash Point of Liquids by Small Scale Closed-Cup Apparatus
D3359 Test Methods for Measuring Adhesion by Tape Test
D3361 Practice for Unfiltered Open-Flame Carbon-Arc Exposures of Paint and Related Coatings
D3363 Test Method for Film Hardness by Pencil Test
D3960 Practice for Determining Volatile Organic Compound (VOC) Content of Paints and Related Coatings
D4060 Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser
D4138 Practices for Measurement of Dry Film Thickness of Protective Coating Systems by Destructive, Cross-Sectioning Means
D4141 Practice for Conducting Black Box and Solar Concentrating Exposures of Coatings
D4145 Test Method for Coating Flexibility of Prepainted Sheet
D4146 Test Method for Formability of Zinc-Rich Primer/Chromate Complex Coatings on Steel
D4147 Practice for Applying Coil Coatings Using The Wire-Wound Drawdown Bar
D4212 Test Method for Viscosity by Dip-Type Viscosity Cups
D4214 Test Methods for Evaluating the Degree of Chalking of Exterior Paint Films
D4287 Test Method for High-Shear Viscosity Using a Cone/Plate Viscometer
D4518 Test Methods for Measuring Static Friction of Coating Surfaces (Withdrawn 2000)[3]
D4585 Practice for Testing Water Resistance of Coatings Using Controlled Condensation
D4587 Practice for Fluorescent UV-Condensation Exposures of Paint and Related Coatings
D5031 Practice for Enclosed Carbon-Arc Exposure Tests of Paint and Related Coatings
D5178 Test Method for Mar Resistance of Organic Coatings
D5402 Practice for Assessing the Solvent Resistance of Organic Coatings Using Solvent Rubs
D5531 Guide for Preparation, Maintenance, and Distribution of Physical Product Standards for Color and Geometric Appearance of Coatings
D5723 Practice for Determination of Chromium Treatment Weight on Metal Substrates by X-Ray Fluorescence
D5796 Test Method for Measurement of Dry Film Thickness of Thin-Film Coil-Coated Systems by Destructive Means Using a Boring Device
D5894 Practice for Cyclic Salt Fog/UV Exposure of Painted Metal, (Alternating Exposures in a Fog/Dry Cabinet and a UV/Condensation Cabinet)
D6093 Test Method for Percent Volume Nonvolatile Matter in Clear or Pigmented Coatings Using a Helium Gas Pycnometer
D6491 Practice for Evaluation of Aging Resistance of Pre-stressed Prepainted Metal In a Dry Heat Test
D6492 Practice for Detection of Hexavalent Chromium On Zinc and Zinc/Aluminum Alloy Coated Steel
D6578 Practice for Determination of Graffiti Resistance
D6665 Practice for Evaluation of Aging Resistance of Pre-stressed Prepainted Metal in a Boiling Water Test
D6695 Practice for Xenon-Arc Exposures of Paint and Related Coatings
D6906 Test Method for Determination of Titanium Treatment Weight on Metal Substrates by Wavelength Dispersive X-Ray Fluorescence
D6944 Practice for Determining the Resistance of Cured Coatings to Thermal Cycling
D7091 Practice for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to Ferrous Metals and Nonmagnetic, Nonconductive Coatings Applied to Non-Ferrous Metals
D7376 Practice for Outdoor Evaluation of Wet Stack Storage Conditions on Coil-Coated Metals
D7639 Test Method for Determination of Zirconium Treatment Weight or Thickness on Metal Substrates by X-Ray Fluorescence
D7835 Test Method for Determining the Solvent Resistance of an Organic Coating using a Mechanical Rubbing Machine
D7869 Practice for Xenon Arc Exposure Test with Enhanced Light and Water Exposure for Transportation Coatings
D7897 Practice for Laboratory Soiling and Weathering of Roofing Materials to Simulate Effects of Natural Exposure on Solar Reflectance and Thermal Emittance
E70 Test Method for pH of Aqueous Solutions With the Glass Electrode
E84 Test Method for Surface Burning Characteristics of Building Materials
E284 Terminology of Appearance

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

E308 Practice for Computing the Colors of Objects by Using the CIE System
E408 Test Methods for Total Normal Emittance of Surfaces Using Inspection-Meter Techniques
E643 Test Method for Ball Punch Deformation of Metallic Sheet Material
E903 Test Method for Solar Absorptance, Reflectance, and Transmittance of Materials Using Integrating Spheres
E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation
E1356 Test Method for Assignment of the Glass Transition Temperatures by Differential Scanning Calorimetry
E1541 Practice for Specifying and Matching Color Using the Colorcurve System (Withdrawn 2007)[3]
E1545 Test Method for Assignment of the Glass Transition Temperature by Thermomechanical Analysis
E1640 Test Method for Assignment of the Glass Transition Temperature By Dynamic Mechanical Analysis
E1808 Guide for Designing and Conducting Visual Experiments
E1918 Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field
E1980 Practice for Calculating Solar Reflectance Index of Horizontal and Low-Sloped Opaque Surfaces
G7 Practice for Atmospheric Environmental Exposure Testing of Nonmetallic Materials
G60 Practice for Conducting Cyclic Humidity Exposures
G85 Practice for Modified Salt Spray (Fog) Testing
G87 Practice for Conducting Moist $SO_2$ Tests
G90 Practice for Performing Accelerated Outdoor Weathering of Nonmetallic Materials Using Concentrated Natural Sunlight
G113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials
G151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources
G152 Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
G153 Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials
G154 Practice for Operating Fluorescent Ultraviolet (UV) Lamp Apparatus for Exposure of Nonmetallic Materials
G155 Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-Metallic Materials

## 3. Terminology

3.1 *Definitions:*

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

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

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

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

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

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

## 4. Significance and Use

4.1 This guide represents a collection of pertinent ASTM test methods used within the coil coatings industry. In the past coil coaters world wide depended on industry standards written by the National Coil 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.

## 7. Liquid Coating Properties

7.1 *Viscosity:*

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

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

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

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

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

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

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

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

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

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

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

| | Section | ASTM Standard |
|---|---|---|
| Liquid Coatings Properties: | 7 | |
| Viscosity: | 7.1 | |
| Ford cup viscosity | 7.1.2 | D1200 |
| Zahn cup viscosity | 7.1.2 | D4212 |
| High-Shear extrusion viscometer | 7.1.3 | D1823 |
| Plastisol and organosol low-shear viscosity | 7.1.4 | D1824 |
| Brookfield-type viscometer | 7.1.5 | D2196 |
| Cone and Plate viscometer | 7.1.6 | D4287 |
| Weight Solids | 7.2 | D2369 |
| Volatile Content | 7.2 | D2369 |
| Volume Solids | 7.3 | D2697, D6093 |
| Fineness of dispersion | 7.4 | D1210 |
| Density (weight per gallon) | 7.5 | D1475 |
| VOC Determination | 7.6 | D3960 |
| pH | 7.7 | E70 |
| Flash Point | 7.8 | D3278 |
| | | |
| Metal Pretreatment: | 8 | |
| Preparation of galvanized steel for painting | 8.2 | D2092 |
| Detecting Cr+6 | 8.3.1 | D6492 |
| X-ray fluorescence, chrome determination | 8.3.2 | D5723 |
| X-ray fluorescence, titanium determination | 8.3.3 | D6906 |
| X-ray fluorescence, zirconium determination | 8.3.4 | D7639 |
| | | |
| Panel Preparation: | 9 | |
| Wire-wound drawdown bars | 9.4.1.1 | D4147 |
| Blade film applicator | 9.4.1.2 | D823 |
| Wet film thickness | 9.5 | D1212 |
| | | |
| Material Properties of a Cured Coil Coating System: | 10 | |
| Dry film thickness (DFT) | 10.1 | |
| DFT, destructive methods | 10.1.1 | |
| DFT, micrometer | 10.1.1.1 | D1005 |
| DFT, microscope | 10.1.1.2 | D4138 |
| DFT, boring method | 10.1.1.3 | D5796 |
| DFT, non-destructive methods | 10.1.2 | |
| DFT, eddy current, non-ferrous base | 10.1.2.1 | D7091 |
| DFT, magnetic flux, ferrous base | 10.1.2.2 | D7091 |
| Color: | 10.2 | |
| Glossary of color | 10.2.1 | E284 |
| Preparation and control of color standards | 10.2.1 | D5531 |
| Color and gloss tolerances | 10.2.1 | D3134 |
| Conducting visual experiments | 10.2.1 | E1808 |
| Color differences by visual evaluation | 10.2.2 | |
| Visual evaluation of color and color difference | 10.2.2.1 | D1729 |
| Color differences by instrumental evaluation | 10.2.3 | |
| Color matching, color curve system | 10.2.3 | E1541 |
| CIE color difference | 10.2.3 | E308 |
| Obtaining special data | 10.2.3 | E1164 |
| Calculation of color differences | 10.2.3 | D2244 |
| Specular gloss measurement | 10.3 | D523 |
| Hardness: | 10.4 | |
| Pencil hardness | 10.4.1 | D3363 |
| Indentation hardness | 10.4.2 | D1474 |
| Flexibility: | 10.5 | |
| Impact resistance | 10.5.2 | D2794 |
| Mandrel bend | 10.5.3 | D522 |
| T bends | 10.5.4 | D4145 |
| Ball punch deformation | 10.5.5 | E643 |
| Draw test | 10.5.6 | D4146 |
| Adhesion: | 10.6 | |
| Cross hatch tape adhesion | 10.6.2 | D3359 |
| Scrape adhesion | 10.6.3 | D2197 |
| Degree of Cure: | 10.7 | |
| Glass transition, TMA | 10.7.2 | E1545 |
| Glass transition, DMA | 10.7.2 | E1640 |
| Glass transition, DSC | 10.7.2 | E1356 |
| Solvent resistance | 10.7.3 | D5402 |
| Solvent resistance, mechanical rub machine | 10.7.3 | D7835 |
| Dry heat test | 10.7.4 | D6491 |
| Boiling water test | 10.7.5 | D6665 |
| Other tests: | 10.8 | |
| Pressure mottling/blocking resistance | 10.8.1 | D3003 |
| Effect of overbaking | 10.8.2 | D2454 |
| Detergent resistance | 10.8.3 | D2248 |

**TABLE 1** *Continued*

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

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

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

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

## 8. Metal Pretreatment

8.1 The successful performance of any coil-coated system is dependent on metal substrate preparation. Metal preparation in the coil coating industry usually consists of one of the following methodologies: clean, rinse, formation of conversion coating, rinse, post-treatment of conversion coating, and dry; or, clean, rinse, application of a roll-on pretreatment, and dry. The metal pretreatment promotes maximum formability and adhesion of the organic coatings to the substrate, as well as promoting environmental exposure resistance, including anticorrosive properties, of the coil coated system. Cleaners, conversion coating treatments, dried-in-place roll-on pretreatments, and post-treatments vary with the performance desired, the coating system used, and the metal substrate. Because there is an interdependency between the cleaning, pretreating, and post-treatment steps, in order to obtain acceptable performance, it is necessary that the reaction times, concentrations, temperatures, and application methods used in the laboratory be as close as possible to those encountered under production condition, and that both laboratory and production conditions be in strict accordance with the pretreatment suppliers' specifications.

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

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

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

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

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

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

## 9. Panel Preparation

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

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

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

9.4 *Drawdowns, Apparatus:*

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

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

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

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

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

## 10. Physical Properties of Cured Coil Coating System

10.1 *Dry Film Thickness (DFT)*—There are several methods used for determining the dry film thickness of a coil coating. The ability to measure the dry film thickness accurately is of utmost importance when one considers that the typical coil coating system (primer+topcoat) is often no more than 25-µ (1-mil) thick. It is always advisable to take at least three DFT measurements to obtain an average value of DFT. There are both non-destructive and destructive means of measuring film thickness for ferrous 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 D1005. The micrometer must be capable of reading to ≤0.0005 in. (0.05 mils).

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

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

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

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

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

10.2 *Color:*

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

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

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

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

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

10.3 *Specular Reflectance:*

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

10.4 *Hardness:*

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

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

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

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

10.5 *Flexibility:*

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

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

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

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

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

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

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 D3359.

10.6.3 *Scrape Adhesion*—Determine the level of scrape adhesion in accordance with Test Method D2197.

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 E1545 (thermomechanical analysis), E1640 (dynamic mechanical analysis), or E1356 (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 D5402 or Test Method D7835.

10.7.4 *Dry Heat Resistance*—Determine the resistance to the aging of prestressed prepainted metal in accordance with Practice D6491.

10.7.5 *Boiling Water Resistance*—Determine the resistance to the aging of prestressed prepainted metal in accordance with Practice D6665.

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 its 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 material in accordance with Test Method D3003.

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 D2454.

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 D2248.

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 D1308.

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 *Tabor 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 coatings's Taber abraser resistance properties in accordance with Test Method D4060.

10.8.5.2 *Falling Abrasive Resistance*—Determine a coating's resistance to falling abrasive in accordance with Test Methods D968.

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 D5178.

10.8.6 *Flame Spread*—Determine the flame spread characteristics of a coating in accordance with Test Method E84.

10.8.7 *Chip Resistance*—Determine the chip resistance of a coating in accordance with Test Method D3170.

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 D4518.

10.8.10 *Thermal Cycling*—Determine the resistance of cured coatings to thermal cycling with Practice D6944.

10.8.11 *Graffiti Resistance*—Determine the resistance to graffiti with Practice D6578.

## 11. Radiative Properties of a Cured Coil Coating System

11.1 *Solar Reflectance:*

11.1.1 The advent of government and private initiatives to improve energy efficiency of buildings and reduce urban heat island effect has brought a series of new measurement methods to the coil coating industry. Primary among these is the measurement of solar reflectance of the coated product over a broad range of wavelengths representative of terrestrial solar radiation from UV to near infrared. The quantity of solar radiation reflected and absorbed by the coated system is an important factor in the heat gain of the building and the surrounding atmosphere. These measurement methods represent field and laboratory techniques for quantifying solar reflectance.

11.1.1.1 Measure the solar reflectance of horizontal and low-slope surfaces in the field using natural sunlight in accordance with Test Method E1918.

11.1.1.2 Measure the solar reflectance of surfaces in the laboratory and field using a portable reflectometer with an integrated source in accordance with Test Method C1549.

11.1.1.3 Measure the solar reflectance and the corresponding spectral reflectance curve of a surface in the laboratory using an instrument with integrating spheres in accordance with Test Method E903.

11.1.1.4 Calculate the solar reflectance index of horizontal and low-sloped opaque surfaces with Practice E1980.

11.1.1.5 Evaluate the effect on solar reflectance and thermal emittance using a laboratory soiling test with Practice D7897.

11.2 *Thermal Emittance:*

11.2.1 The thermal emittance or emissivity of a coated system represents the fraction of thermal infrared energy radiated by the surface relative to that radiated by a black body at the same temperature. Emissivity is also dependent upon direction or angle relative to the surface. It may be measured normal (perpendicular) to the surface or integrated over all directions (hemispherical).

11.2.1.1 Measure emittance (emissivity) integrated over all directions (hemispherical) above a point on the surface in accordance with Test Method C1371.

11.2.1.2 Measure emittance (emissivity) normal (perpendicular) to the surface in accordance with Test Method E408.

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

12.1 *Real-Time Weathering:*

12.1.1 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 Practices D1014 and G7, 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.

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

12.1.2.1 *Blistering*—Test Method D714.

12.1.2.2 *Chalking*—Test Method D4214.

12.1.2.3 *Checking*—Test Method D660.

12.1.2.4 *Cracking*—Test Method D661.

12.1.2.5 *Rusting*—Test Method D610.

12.1.2.6 *Corrosion*—Test Method D1654.

12.1.3 Exposure of coil-coated metals to improper outdoor storage conditions can allow degradation of the coated metal system. Water ingress between stacked building panels may cause corrosion and blistering of the coated system. A wet stack storage test designed to simulate these conditions can be used to assess the relative resistance of the system to degradation.

12.1.3.1 Assess the relative resistance of coil-coated metals to improper outdoor wet storage conditions in accordance with Practice D7376.

12.2 *Accelerated Corrosion and Environmental Resistance Characteristics:*

12.2.1 *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 B117.

12.2.2 *Humidity*—Determine the humidity resistance of coil-coated material in accordance with Practice D2247 and D1735. 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 B117).

12.2.3 *Controlled Condensation*—Determine the resistance of coil-coated material to water in accordance with Practice D4585 (also known as "Cleveland Condensing" test).

12.2.4 *Water Immersion*—Determine the resistance of a coil-coated material to water immersion in accordance with Practice D870.

12.2.5 *Cyclic Humidity and Salt Spray*—Alternatives to a constant state of 100 % humidity are Test Methods G60 (cyclic humidity), Practices G85 (cyclic salt spray), and D5894 (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.

12.2.6 *Moist $SO_2$ ("Kesternich")*—To assess to effect of exposure to $SO_2$, test in accordance with Practice G87.

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 G87 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.

12.2.7 *Copper-Accelerated Salt Spray (CASS)*—This is another test often used when aluminum substrate is involved. Test in accordance with Test Method B368.

12.2.8 *Filiform Corrosion*—Evaluate a coil coating system's tendency to display filiform resistance in accordance with Guide D2803.

12.2.9 *Specification for Reagent Water*—Should reagent water information be needed, test in accordance with Specification D1193.

12.3 *Accelerated Weathering:*

12.3.1 *Accelerated Weathering*—Accelerated 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 conditions 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 300 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. The use of accelerated testing devices that simulate the earth's full solar spectral power distribution (SPD) is important in evaluating the weathering performance of both colorless and colored polymeric materials. The wavelengths of solar UV and some of the visible portion absorbed by polymeric materials are responsible for initiating their degradation. The near-infrared and visible wavelengths absorbed play a key role in heating the samples, thus accelerating the secondary reactions resulting from bond breakage by the actinic radiation in the UV and visible regions. Simulation of the differences in acceleration of the secondary reactions in polymeric materials under environmental conditions to simulate their relative performances depends on the degree of conformance to the solar visible and near-infrared SPD.

12.3.2 *Dew Cycle (Unfiltered Open-Flame Carbon Arc)*—Test the response of the coating to dew cycle exposure in accordance with Practices D3361.

12.3.3 *Filtered, Open-Flame Carbon Arc Weather-Ometer*—Test in accordance with Practices D822 or G152 and G151.

12.3.4 *Fluorescent UV-Condensation Device*—Test in accordance with Practices D4587 or G154 and G151.

12.3.5 *Enclosed Carbon Arc Device*—Test in accordance with Practices D5031 or G153 and G151.

12.3.6 *Xenon Arc Device*—Test in accordance with Practices G151, G155, D6695, or D7869.

12.3.7 *Accelerated Outdoor Tests (Black Box, Fresnel Device)*—Test in accordance with Practices D4141 or G90.

NOTE 5—Sections 12.3.2 – 12.3.7 reference multiple cycles and test methods. Users should review the various test cycles available in each method and choose one best suited for their application. Furthermore, each method will have different test conditions that may result in different levels and types of degradation. These methods are not equivalent.

## 13. Keywords

13.1 absorbance; accelerated; acetic acid; adhesion; chip resistance; chromate; coil coatings; color; cone and plate; cyclic; density; dew cycle; film thickness; fame 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