Designation: D 5031 – 01

Standard Practice for Enclosed Carbon-Arc Exposure Tests of Paint and Related Coatings[1]

This standard is issued under the fixed designation D 5031; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the selection of test conditions for accelerated exposure testing of coatings and related products in enclosed carbon arc devices operated according to Practices G 151 and G 153. This practice also covers the preparation of test specimens, the test conditions suited for coatings, and the evaluation of test results. Table 1 describes commonly used test conditions.

NOTE 1—Previous versions of this practice referenced carbon arc devices described by Practice G 23, which described very specific equipment designs. Practice G 23 has been withdrawn and replaced by Practice G 151, which describes performance criteria for all exposure devices that use laboratory light sources, and by Practice G 153, which gives requirements for exposing nonmetallic materials in enclosed carbon-arc devices.

1.2 This practice does not cover filtered open-flame carbon-arc exposures of paints and related coatings, which is described in Practice D 822. Another procedure for exposing these products is covered by Practice D 3361, in which the specimens are subjected to radiation from an unfiltered open-flame carbon arc that produces shorter wavelengths and higher levels of short wavelength radiation than filtered open flame or enclosed carbon arcs.

NOTE 2—Practice D 3361 requires use of open-flame carbon-arc apparatus with automatic humidity control.

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:*

D 358 Specification for Wood to Be Used as Panels in Weathering Tests of Coatings[2]

D 523 Test Method for Specular Gloss[3]

D 609 Practice for Preparation of Cold-Rolled Steel Panels for Testing Paint, Varnish, Conversion Coatings, and Related Coating Products[3]

D 610 Test Method for Evaluating Degree of Rusting on Painted Steel Surfaces[2]

D 659 Method of Evaluating Degree of Chalking of Exterior Paints[4]

D 660 Test Method for Evaluating Degree of Checking of Exterior Paints[3]

D 662 Test Method for Evaluating Degree of Erosion of Exterior Paints[3]

D 714 Test Method for Evaluating Degree of Blistering of Paints[3]

D 772 Test Method for Evaluating Degree of Flaking (Scaling) of Exterior Paints[3]

D 822 Practice for Conducting Tests on Paint and Related Coatings and Materials Using Filtered Open-Flame Carbon-Arc Light and Water Exposure Apparatus[3]

D 823 Practices for Producing Films of Uniform Thickness of Paint, Varnish, and Related Products on Test Panels[3]

D 1005 Test Methods for Measurement of Dry-Film Thickness of Organic Coatings Using Micrometers[3]

D 1186 Test Methods for Nondestructive Measurement of Dry Film Thickness of Nonmagnetic Coatings Applied to a Ferrous Base[3]

D 1400 Test Method for Nondestructive Measurement of Dry Film Thickness of Nonconductive Coatings Applied to a Nonferrous Metal Base[3]

D 1729 Practice for Visual Evaluation of Colors and Color Differences of Diffusely Illuminated Opaque Materials[3]

D 1730 Practices for Preparation of Aluminum and Aluminum-Alloy Surfaces for Painting[5]

D 2244 Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates[3]

D 2616 Test Method for Evaluation of Visual Color Difference with a Gray Scale[3]

D 3361 Practice for Operating Light- and Water-Exposure Apparatus (Unfiltered Carbon-Arc Type) for Testing Paint,

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[1] This practice is under the jurisdiction of ASTM Committee D01 on Painted and Related Coatings, Materials, and Applications and is the direct responsibility of Subcommittee D01.27 on Accelerated Testing.

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

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

[4] Discontinued 1989; see *1990 Annual Book of ASTM Standards*, Vol 06.01.

[5] *Annual Book of ASTM Standards*, Vol 02.05.

TABLE 1 Test Cycles Commonly Used for Enclosed Carbon-Arc Exposure Testing of Paints and Related Coatings[A]

Cycle Number	Cycle Description	Uninsulated Black Panel Temperature[B] (°C)	(°F)	Typical Uses[C]
1	Continuous light 102 min light only at 50 ± 5 % RH 18 min light and water spray[D] Repeated continuously	63 ± 2.5	145 ± 5	General coatings and historical convention[E]
2	18 h continuous light using: 102 min light only at 50 ± 5 % RH 18 min light and water spray	63 ± 2.5	145 ± 5	General coatings
	6 h dark using: 95 % relative humidity (no water spray) Repeated continuously	24 ± 1.5	75 ± 3	
3	48 min light at 50 ± 5 % RH 12 min light and water spray Repeated continuously	63 ± 2.5	145 ± 5	Coatings used in original equipment manufacturing
4	4 h light at 50 ± 5 % RH 4 h dark with water spray Repeated continuously	63 ± 2.5	145 ± 5	Exterior pigmented stains
5	12 h light at 50 ± 5 % RH 12 h dark water spray Repeated continuously	63 ± 2.5	145 ± 5	Exterior wood stains and clears
6	8 h light at 50 ± 5 % RH 10 h light and water spray 6 h dark with water spray Repeated continuously	63 ± 2.5	145 ± 5	Marine enamels

[A] The cycles described are not listed in any order indicating importance, and are not necessarily recommended for the applications listed.
[B] Unless otherwise indicated, black panel temperatures apply during the light-only portion of the cycle. The equilibrium black panel temperature is obtained without a spray period. For light intervals less than 30 min, the black panel temperature might not reach equilibrium.
[C] Typical uses do not imply that results from exposures of these materials according to the cycle described will correlate to those from actual use conditions.
[D] Unless otherwise specified, water spray refers to water sprayed on the exposed surfaces of the test specimens.
[E] Historical convention has established this as a very commonly used test cycle. This cycle may not adequately simulate the effects of outdoor exposure.

Varnish, Lacquer, and Related Products Using the Dew Cycle[3]
D 3980 Practice for Interlaboratory Testing of Paint and Related Materials[6]
D 4214 Test Methods for Evaluating Degree of Chalking of Exterior Paint Films[3]
D 5870 Practice for Calculating Property Retention Index of Plastics[7]
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[8]
E 1347 Test Method for Color and Color-Difference Measurement by Tristimulus (Filter) Colorimetry[3]
G 23 Practice for Operating Light- and Water-Exposure Apparatus (Carbon-Arc Type) With and Without Water for Exposure of Nonmetallic Materials[9]
G 113 Terminology Relating to Natural and Artificial Weathering Tests of Nonmetallic Materials[10]
G 141 Guide for Addressing Variability in Exposure Testing on Nonmetallic Materials[10]
G 147 Practice for Conditioning and Handling of Nonmetallic Materials for Natural and Artificial Weathering Tests[10]
G 151 Practice for Exposing Nonmetallic Materials in Accelerated Test Devices That Use Laboratory Light Sources[10]
G 152 Practice for Operating Open Flame Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials[10]
G 153 Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials[10]
G 169 Guide for Application of Basic Statistical Methods to Weathering Tests[10]

3. Terminology

3.1 The definitions given in Terminology G 113 are applicable to this practice.

4. Significance and Use

4.1 The ability of a paint or coating to resist deterioration of its physical and optical properties caused by exposure to light, heat, and water can be very significant for many applications. This practice is intended to induce property changes associated with end-use conditions, including the effects of sunlight, moisture, and heat. The exposure used in this practice is not intended to simulate the deterioration caused by localized weather phenomena such as atmospheric pollution, biological attack, and saltwater exposure.

4.2 *Cautions*—Variation in results may be expected when different operating conditions are used. Therefore, no reference to the use of this practice shall be made unless accompanied by a report prepared according to Section 10 that describes the specific operating conditions used. Refer to Practice G 151 for detailed information on the caveats applicable to use of results obtained according to this practice.

NOTE 3—Additional information on sources of variability and on strategies for addressing variability in the design, execution, and data analysis of laboratory accelerated exposure tests is found in Guide G 141.

4.2.1 The spectral power distribution of light from an

[6] Discontinued 1998; see *1997 Annual Book of ASTM Standards*, Vol 06.01.
[7] *Annual Book of ASTM Standards*, Vol 08.03.
[8] *Annual Book of ASTM Standards*, Vol 14.02.
[9] Discontinued 2000; see *1999 Annual Book of ASTM Standards*, Vol 14.04.
[10] *Annual Book of ASTM Standards*, Vol 14.04.

enclosed carbon arc is significantly different from that produced in light and water exposure devices using other carbon-arc configurations or other light sources. The type and rate of degradation and the performance rankings produced by exposures to enclosed carbon arcs can be much different from those produced by exposures to other types of laboratory light sources.

4.2.2 Interlaboratory comparisons are valid only when all laboratories use the same type of carbon arc, filters, and exposure conditions.

4.3 Reproducibility of test results between laboratories has been shown to be good when the stability of materials is evaluated in terms of performance ranking compared to other materials or to a control.[11,12] Therefore, exposure of a similar material of known performance (a control) at the same time as the test materials is strongly recommended. It is recommended that at least three replicates of each material be exposed to allow for statistical evaluation of results.

4.4 Test results will depend upon the care that is taken to operate the equipment according to Practice G 153. Significant factors include regulation of line voltage, freedom from salt or other deposits from water, temperature and humidity control, and conditions of the electrodes.

4.5 *All references to exposures in accordance with this practice must include a complete description of the test cycle used.*

5. Apparatus

5.1 Use enclosed carbon-arc apparatus that conforms to the requirements defined in Practices G 151 and G 153.

5.2 Unless otherwise specified, the spectral power distribution of the enclosed carbon arc shall conform to the requirements in Practice G 153 for the enclosed carbon arc.

6. Hazards

6.1 **Warning—**In addition to other precautions, never look directly at the carbon arc because UV radiation can damage the eye. Most carbon-arc machines are equipped with door safety switches, but users of old equipment must be certain to turn off the power to the carbon arc before opening the test-chamber door.

6.2 The burning carbon rods used in these devices become very hot during use. Make sure to allow at least 15 min for the arcs to cool after the device is turned off before attempting to change the carbon rods.

6.3 Carbon residue and ash are known respiratory irritants. Wear an appropriate high-efficiency dust respirator, gloves, and safety glasses when handling or changing carbon rods. Make sure to wash any carbon residue from hands or arms prior to eating or drinking.

7. Test Specimens

7.1 Apply the coating to flat (plane) panels with the substrate, method of preparation, method of application, coating system, film thickness, and method of drying consistent with the anticipated end use, or as mutually agreed upon between the producer and user.

7.2 Panel specifications and methods of preparation include but are not limited to Practices D 609 or D 1730, or Specification D 358. Select panel sizes suitable for use with the exposure apparatus.

7.3 Coat test panels in accordance with Test Methods D 823, then measure the film thickness in accordance with an appropriate procedure selected from Test Methods D 1005, D 1186, or D 1400. Nondestructive methods are preferred because panels so measured need not be repaired.

7.4 Prior to exposing coated panels in the apparatus, condition them at 23 ± 2°C (73 ± 3°F) and 50 ± 5 % relative humidity for one of the following periods in accordance with the type of coating:

Baked coatings	24 h
Radiation-cured coatings	24 h
All other coatings	7 days

7.4.1 Other procedures for preparation of test specimens may be used if agreed upon by all interested parties.

7.5 Mount specimens in holders so that only the minimum specimen area required for support by the holder is covered. Do not use this covered area of the specimen as part of the test area.

7.6 Unless otherwise specified, expose at least three replicate specimens of each test and control material.

7.7 Follow the procedures described in Practice G 147 for identification and conditioning and handling of specimens of test, control, and reference materials prior to, during, and after exposure.

7.8 Do not mask the face of a specimen for the purpose of showing on one panel the effects of various exposure times. Misleading results may be obtained by this method, since the masked portion of the specimen is still exposed to temperature and humidity cycles that in many cases will affect results.

7.9 Retain a supply of unexposed file specimens of all materials evaluated.

7.9.1 When destructive tests are run, it is recommended that a sufficient number of file specimens be retained so that the property of interest can be determined on unexposed file specimens each time exposed materials are evaluated.

NOTE 4—Since the stability of the file specimen may also be time dependent, users are cautioned that over prolonged exposure periods, or where small differences in the order of acceptable limits are anticipated, comparison of exposed specimens with the file specimen may not be valid. Nondestructive instrumental measurements are recommended whenever possible.

7.10 Specimens should not ordinarily be removed from the exposure apparatus for more than 24 h, then returned for additional tests, since this does not produce the same results on all materials as tests run without this type of interruption. When specimens are removed from the exposure apparatus for 24 h or more, then returned for additional exposure, report the elapsed time as noted under Section 10.

8. Procedure

8.1 Table 1 lists several exposure cycles that are used for enclosed carbon arc exposures of nonmetallic materials. Obtain

[11] Fischer, R., "Results of Round-Robin Studies of Light- and Water-Exposure Standard Practices," *Accelerated and Outdoor Durability Testing of Organic Materials, ASTM STP 1202*, ASTM, 1993.

[12] Ketola, W., and Fischer, R., "Characterization and Use of Reference Materials in Accelerated Durability Tests," *VAMAS Technical Report No. 30*, NIST, June 1997.

mutual agreement between all concerned parties for the specific exposure cycle used. Additional intervals and methods of wetting, by spray, condensation, or both, may be substituted upon agreement among the concerned parties.

NOTE 5—Each set point and its tolerances found in Table 1 represent an operational control point for equilibrium conditions at a single location in the cabinet, which may not necessarily represent the uniformity of those conditions throughout the cabinet. ASTM Subcommittee G03.03 is working to refine these tolerances and address the uniformity issue.

8.1.1 Unless otherwise specified, maintain relative humidity at 50 ± 5 % equilibrium during the light-only interval.

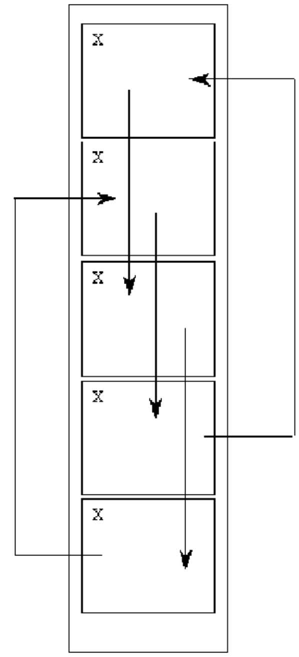
8.2 If no other cycle is specified, use Cycle No. 1.

8.3 Mount test specimens in the device following the placement and specimen repositioning procedures described in Practice G 152. It is recommended that all unused spaces in the specimen exposure area be filled with blank metal panels.

8.4 If the irradiance uniformity within the exposure area does not meet the requirements of Practice G 151 for exposure without repositioning, use one of the procedures described in Practice G 153 to ensure that specimens receive as uniform a radiant exposure as possible.

8.4.1 If specimen repositioning is used, and no repositioning schedule is specified, use the following procedure for specimen repositioning:

8.4.2 Once per week, move all specimens in the top half of the specimen exposure area to the bottom half and move all holders in the bottom half of the exposure area to the top half of the exposure area. If there are an odd number of specimens, move the two at the bottom of the exposure area to the top of the exposure area (keeping the relative position of these two panels the same) and slide all other specimens two spaces down. This is illustrated in Fig. 1:



NOTE—"X" denotes specimen orientation.

FIG. 1 Repositioning Diagram When There Are an Odd Number of Specimens in a Holder

NOTE 6—Incident energy at the top and bottom of the specimen rack is often only 60 to 70 % of that at the center. This condition requires that the procedures described in 8.4 be followed to assure uniformity of radiant exposure.

8.5 *Water Purity*:

8.5.1 The purity of water used for specimen spray is very important. Without proper treatment to remove cations, anions, organics, and particularly silica, exposed panels will develop spots or stains that may not occur in exterior exposures.

8.5.2 Follow the requirements for water purity described in Practice G 151.

8.5.3 If specimens are found to have deposits or stains after exposure in the apparatus, the water purity must be checked to determine if it meets the requirements of 8.5.2. On some occasions, exposed specimens can be contaminated by deposits from bacteria that can grow in the purified water used for specimen spray. If bacterial contamination is detected, the entire system used for specimen water spray must be flushed with chlorine and thoroughly rinsed prior to resuming exposures.

8.5.4 The typical temperature of water used for specimen spray is 21 ± 5°C (70 ± 9°F). However, if ambient water temperature is low and a holding tank is not used to store purified water, the temperature of water used for specimen spray may be below the typical range given above.

8.5.5 When the water purity requirements above are met and there is disagreement between parties on the extent of problems caused by stain or deposit, run referee tests in at least one other laboratory that can meet the water quality requirements described in 8.4.

8.5.6 For devices with humidity control, it is recommended that deionized water be used when generating water vapor to control humidity.

8.6 Some tests for lightfastness are run without any specimen wetting. When this type of test is required, omit the period where water is sprayed on specimens.

8.7 Identification of any control specimen used shall accompany the report.

9. Periods of Exposure and Evaluation of Test Results

9.1 In most cases, periodic evaluation of test and control materials is necessary to determine the variation in magnitude and direction of property change as a function of exposure time or radiant exposure.

9.2 The time or radiant exposure necessary to produce a defined change in a material property can be used to evaluate or rank the stability of materials. This method is preferred over evaluating materials after an arbitrary exposure time or radiant exposure.

9.2.1 Exposure to an arbitrary time or radiant exposure may be used for the purpose of a specific test if agreed upon between the parties concerned or if required for conformance to a particular specification. When a single exposure period is used, select a time or radiant exposure that will produce the largest performance differences between the test materials or between the test material and the control material.

9.2.2 The minimum exposure time used shall be that necessary to produce a substantial change in the property of interest for the least stable material being evaluated. An exposure time that produces a significant change in one type of material cannot be assumed to be applicable to other types of materials.

9.2.3 The relation between time to failure in an exposure conducted according to this practice and service life in an outdoor environment requires determination of a valid acceleration factor. Do not use arbitrary acceleration factors relating time in an exposure conducted according to this practice and time in an outdoor environment, because they can give erroneous information. The acceleration factor is material dependent and is only valid if it is based on data from a sufficient number of separate exterior and laboratory accelerated exposures so that results used to relate times to failure in each exposure can be analyzed using statistical methods.

NOTE 7—An example of a statistical analysis using multiple laboratory and exterior exposures to calculate an acceleration factor is described by J.A. Simms.[13] See Practice G 151 for more information and additional cautions about the use of acceleration factors.

9.3 After each exposure increment, determine the changes in exposed specimens. Test Methods D 523, D 610, D 659, D 660, D 662, D 714, D 772, D 2244, D 2616, D 4214, or E 1347, or Practice D 1729 may be used. Consider product use requirements when selecting appropriate methods.

9.3.1 Other methods for evaluating test specimens may be used if agreed upon between all interested parties.

NOTE 8—For some materials, changes may continue after the specimen has been removed from the exposure apparatus. Measurements (visual or instrumental) should be made within a standardized time period or as agreed upon between interested parties. The standardized time period needs to consider conditioning prior to testing.

9.4 It is recommended that the following procedure be followed when results from exposures conducted according to this practice are used in specifications.

9.4.1 If a standard or specification for *general use* requires a defined property level after a specific time or radiant exposure in an exposure test conducted according to this practice, base the specified property level on results from round-robin experiments run to determine the test reproducibility for the exposure and property measurement procedures. Conduct these round robins according to Practice E 691 or D 3980 and include a statistically representative sample of all laboratories or organizations that would normally conduct the exposure and property measurement.

9.4.2 If a standard or specification for *use between two or three parties* requires a defined property level after a specific time or radiant exposure in an exposure test conducted according to this practice, base the specified property level on at least two independent experiments run in each laboratory to determine the reproducibility for the exposure and property measurement process. The reproducibility of the exposure/property measurement process is then used to determine the maximum or minimum level of property after the exposure that is mutually agreeable to all parties.

9.4.3 When reproducibility in results from an exposure test conducted according to this practice has not been established through round robin testing, specify performance requirements for materials in terms of comparison (ranked) to a control material. All specimens shall be exposed simultaneously in the same device. All concerned parties must agree on the specific control material used.

9.4.3.1 Conduct analysis of variance to determine whether the differences between test materials and any control materials used are statistically significant. Expose replicates of the test specimen and the control specimen so that statistically significant performance differences can be determined.

NOTE 9—Fischer illustrates use of rank comparison between test and control materials in specifications.[14]

NOTE 10—Guide G 169 includes examples showing use of analysis of variance to compare materials.

10. Report

10.1 Report the following information:

10.1.1 Type and model of exposure device.

10.1.2 Type of light source.

10.1.3 Average distance from specimens to light source.

10.1.4 Type and age of filters at the beginning of the exposure, and whether any of the filters were replaced during the period of exposure.

10.1.5 Type of black panel (uninsulated or insulated) used.

10.1.6 If required, irradiance in $W/m^2 \cdot nm$, or radiant exposure in J/m^2, at the sample location, and the wavelength region in which the measurements were made.

10.1.6.1 Do not report irradiance or radiant exposure unless direct measurement of spectral irradiance was made during the exposure.

10.1.7 Elapsed exposure time.

10.1.8 Light and dark-water-humidity cycle employed.

10.1.9 Operating black panel temperature.

10.1.10 Operating relative humidity.

10.1.11 Type of spray water.

10.1.11.1 Total solids and silica level of water used for specimen spray (if above limits specified in 8.5).

10.1.12 Type of spray nozzle.

10.1.13 Specimen repositioning procedure.

10.1.14 Results of property tests. Where retention of characteristic property is reported, calculate results according to Practice D 5870.

NOTE 11—In some cases, exposures are conducted by a contracting agency but property tests are conducted by the contracting party. In these cases, the agency that conducts the exposures cannot report results from property tests.

11. Precision and Bias

11.1 *Precision*—The repeatability and reproducibility of results obtained in exposures conducted according to this practice will vary with the materials being tested, the material property being measured, and the specific test conditions and cycles that are used.

11.2 *Bias*—Bias can not be determined because no acceptable standard weathering reference materials are available.

[13] Simms, J. A., *Journal of Coatings Technology*, Vol 50, 1987, pp. 45–53.

[14] Fischer, R., Ketola, W., "Impact of Research on Development of ASTM Durability Testing Standards," *Durability Testing of Non-Metallic Materials, ASTM STP 1294*, ASTM, 1995.

12. Keywords

12.1 carbon arc; degradation; exposure; light exposure; ultraviolet; weathering