INTERNATIONAL

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Standard Test Method for Thermal Endurance of Rigid Electrical Insulating Materials[1]

This standard is issued under the fixed designation D2304; 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 test method[2] provides procedures for evaluating the thermal endurance of rigid electrical insulating materials. Dielectric strength, flexural strength, or water absorption are determined at room temperature after aging for increasing periods of time in air at selected-elevated temperatures. A thermal-endurance graph is plotted using a selected end point at each aging temperature. A means is described for determining a temperature index by extrapolation of the thermal endurance graph to a selected time.

1.2 This test method is most applicable to rigid electrical insulation such as supports, spacers, voltage barriers, coil forms, terminal boards, circuit boards and enclosures for many types of application where retention of the selected property after heat aging is important.

1.3 When dielectric strength is used as the aging criterion, it is also acceptable to use this test method for some thin sheet (flexible) materials, which become rigid with thermal aging, but is not intended to replace Test Method D1830 for those materials which must retain a degree of flexibility in use.

1.4 This test method is not applicable to ceramics, glass, or similar inorganic materials.

1.5 The values stated in metric units are to be regarded as standard. Other units (in parentheses) are provided for information.

1.6 When determining the thermal endurance of rigid EIM, the basic concepts in this standard follow IEEE 1, IEEE 98, and IEEE 101.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* A specific warning statement is given in 11.3.4.

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

[1] This test method is under the jurisdiction of ASTM Committee D09 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.07 on Electrical Insulating Materials.

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[2] This test method is a revision of a procedure written by the Working Group on Rigid Electrical Insulating Materials of the Subcommittee on Thermal Evaluation, IEEE Electrical Insulation Committee, which was presented as CP 59-113 at the IEEE Winter General Meeting Feb. 1–6, 1959. See references at end of this test method.

***A Summary of Changes section appears at the end of this standard**

2. Referenced Documents

2.1 *ASTM Standards:*[3]

D149 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies
D229 Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation
D570 Test Method for Water Absorption of Plastics
D790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
D1830 Test Method for Thermal Endurance of Flexible Sheet Materials Used for Electrical Insulation by the Curved Electrode Method
D5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation

2.2 *IEEE:*[4]

No. 1 General Principles Upon Which Temperature Limits Are Based in the Rating of Electric Equipment
No. 98 Guide for the Preparation of Test Procedures for the Thermal Evaluation of Electrical Insulating Materials
No. 101 Guide for the Statistical Analysis of Test Data

3. Terminology

3.1 *Definitions:*

3.1.1 *Arrhenius plot, n*—a graph of the logarithm of thermal life as a function of the reciprocal of absolute temperature.

3.1.1.1 *Discussion*—
This is normally depicted as the best straight line fit, determined by least squares, of end points obtained at aging temperatures. It is important that the slope, which is the activation energy of the degradation reaction, be approximately constant within the selected temperature range to ensure a valid extrapolation.

3.1.2 *temperature index, n*—a number which permits comparison of the temperature/time characteristics of an electrical insulating material, or a simple combination of materials, based on the temperature in degrees Celsius which is obtained by extrapolating the Arrhenius plot of life versus temperature to a specified time, usually 20 000 h.

3.1.3 *thermal life, n*—the time necessary for a specific property of a material, or a simple combination of materials, to degrade to a defined end point when aged at a specified temperature.

3.1.4 *thermal life curve, n*—a graphical representation of thermal life at a specified aging temperature in which the value of a property of a material, or a simple combination of materials, is measured at room temperature and the values plotted as a function of time.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *rigid electrical insulating material, n*—an electrical insulating material having a minimum flexural modulus of ~~690 MPa~~ 690 MPa and minimum use thickness of ~~0.5 mm (0.02 in.).~~ 0.5 mm (0.02 in.). It is generally used as terminal boards, spacers, coil forms, voltage barriers, and circuit boards.

4. Hazards

4.1 *High Voltage:*

4.1.1 Lethal voltages are a potential hazard during the performance of this test. It is essential that the test apparatus, and all associated equipment electrically connected to it, be properly designed and installed for safe operation.

4.1.2 Solidly ground all electrically conductive parts which it is possible for a person to contact during the test.

4.1.3 Provide means for use at the completion of any test to ground any parts which were at high voltage during the test or have the potential for acquiring an induced charge during the test or retaining a charge even after disconnection of the voltage source.

[3] 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.

[4] Available from the Institute of Electrical and Electronics Engineers, 445 Hoes Ln., P.O. Box 1331, Piscataway, NJ 08854-1331.

4.1.4 Thoroughly instruct all operators as to the correct procedures for performing tests safely.

4.1.5 When making high voltage tests, particularly in compressed gas or in oil, it is possible for the energy released at breakdown to be sufficient to result in fire, explosion, or rupture of the test chamber. Design test equipment, test chambers , and test specimens so as to minimize the possibility of such occurrences and to eliminate the possibility of personal injury. If the potential for fire exists, have fire suppression equipment available. See 11.3.4.

5. Summary of Test Method

5.1 Test specimens are aged in air at three or preferably four temperatures above the expected use temperature. The aging temperatures are selected so that the thermal life is at least ~~100 h~~ 100 h at the highest aging temperature and ~~5000 h~~ 5000 h at the lowest aging temperature. A thermal-life curve is plotted for each aging temperature. The values of thermal life determined from the thermal-life curve are used to plot the thermal-endurance graph. A temperature index is determined from the thermal-endurance graph for each aging criterion used. (It is possible to obtain different values for the thermal index of a material with different aging criteria.)

6. Significance and Use

6.1 Thermal degradation is often a major factor affecting the life of insulating materials and the equipment in which they are used. The temperature index provides a means for comparing the thermal capability of different materials in respect to the degradation of a selected property (the aging criterion). This property needs to directly or indirectly represent functional needs in application. For example, it is possible that a change in dielectric strength will be of direct, functional importance. However, more often it is possible that a decrease in dielectric strength will indirectly indicate the development of undesirable cracking (embrittlement). A decrease in flexural strength has the potential to be of direct importance in some applications, but also has the potential to indirectly indicate a susceptibility to failure in vibration. Often, it is necessary that two or more criteria of failure be used; for example, dielectric strength and flexural strength.

6.2 Other factors, such as vibration, moisture and contaminants, have the potential to cause failure after thermal degradation takes place. In this test method, water absorption provides one means to evaluate such considerations.

6.3 For some applications, the aging criteria in this test method will not be the most suitable. Other criteria, such as elongation at tensile or flexural failure, or resistivity after exposure to high humidity or weight loss, have the potential to serve better. The procedures in this test method have the potential to be used with such aging criteria. It is important to consider both the nature of the material and its application. For example, it is possible that tensile strength will be a poor choice for glass-fiber reinforced laminates, because it is possible that the glass fiber will maintain the tensile strength even when the associated resin is badly deteriorated. In this case, flexural strength is a better criterion of thermal aging.

6.4 When dictated by the needs of the application, it is possible that an aging atmosphere other than air will be needed and used. For example, thermal aging can be conducted in an oxygen-free, nitrogen atmosphere.

7. End Point

7.1 An expression of the thermal life of a material, even for comparative purposes only, inevitably involves the choice of an end point. The end point is one of the following 4 criteria: a fixed magnitude of the property criterion, a percentage reduction from its initial magnitude, the minimum magnitude obtainable with time (that is, when change with time ceases), or a fixed degrading change rate (that is, a fixed value for the negative derivative of property with respect to time).

7.2 Experience has shown that the choice of an end point can affect the comparative thermal life. A choice of end points is guided by the limiting requirements imposed on the insulation by the manner and conditions of use in the complete system. End points are not specified in this test method. The first concern is to determine the values of the chosen properties as a function of time of thermal exposure at specified temperatures. The properties are determined at various intervals of time until a practical minimum or maximum magnitude, whichever is applicable, is reached. The data that result are thus universal, that is, usable for any subsequently chosen end point as determined by the specific application of the rigid electrical insulation.

7.3 The specification for each material needs to state the end point to be used.

8. Aging Ovens

8.1 The accuracy of the test results will depend on the accuracy with which the exposure temperature of the test specimens is known. Experience has shown, as indicated in Table 1, that the thermal life is approximately halved for a ~~10°C~~10 °C increase in exposure temperature.

8.2 Use aging ovens that conform to the requirements of Type I of Specification D5423.

9. Test Specimen

9.1 The accuracy of the test results depends significantly upon the number of specimens exposed at each temperature and the dispersion of the test results. The larger the individual deviations from the mean, the greater is the number of test specimens needed to achieve satisfactory accuracy. Experience has shown that a minimum of five test specimens needs to be used at each exposure temperature. A separate group of test specimens is required for each exposure period.

9.2 The rate of deterioration will be significantly influenced by specimen thickness. Consequently it is important to test specimens of the same nominal thickness when comparing the thermal degradation of two or more materials unless information relating degradation to thickness is available that indicates the contrary. This test method specifies the specimen size, including thickness, for each property selected.

PROCEDURES

10. Oven Aging (Thermal Exposure)

10.1 Factors such as moisture, chemical contamination, and mechanical stress or vibration usually do not in themselves cause failure, but are factors that have the potential to result in failure only after the material has been weakened by thermal deterioration. For this reason, exposure to elevated temperatures is the primary deteriorating influence considered in this test method.

10.2 Table 1 is intended as a guide for the selection of thermal exposure. Select times and temperatures from those given in this table. The exposure times given are approximately equal to the average estimated life at each exposure temperature based on thermal aging data obtained on insulating materials and systems. The potential exists that this table will be revised as a result of experience. The potential that either the time or the temperature will be adjusted to make the best use of available oven facilities.

TABLE 1 Temperature and Exposure Time in Days

Exposure Temperature, °C	Estimated Hottest-Spot Temperature Range, °C				
	100 to 120	125 to 145	150 to 170	175 to 195	200 to 240
300	...	...	...	...	10
290	...	...	...	...	20
280	...	...	...	...	40
270	...	...	...	...	70
260	...	...	...	...	140
250	...	...	...	10	280
240	...	...	...	20	490
230	...	...	...	40	...
220	...	...	10	70	...
210	...	...	20	140	...
200	...	10	40	280	...
190	...	20	70	490	...
180	10	40	140	...	...
170	20	70	280	...	...
160	40	140	490	...	...
150	70	280	...	...	...
140	140	490	...	...	...
130	280	...	...	...	...
120	490	...	...	...	...

10.3 Age at a minimum of three and preferably four temperatures. Choose the lowest temperature to be less than ~~25°C~~25 °C above the hottest-spot temperature expected in use so that the thermal life is at least 5000 h. Select the highest temperature so that the thermal life is at least 100 h. If possible, for best results, the aging temperatures need to differ from each other by at least ~~20°C.~~20 °C.

10.4 For an unknown material, the selection of the appropriate aging temperatures will require a short exploratory test performed at the highest likely aging temperature. Results from thermal aging tests for a material with similar composition have the potential to provide clues for an appropriate selection of the first exploratory temperature. The chemical composition of the material to be tested, if known, has the potential to also provide a means for estimating the first aging temperature to be used. Additional tests can then be made at lower or higher temperatures as indicated by the first exploratory test. (See Table 1 and 10.3.)

10.5 Place a sufficient number of specimens to conduct the tests used for the selected aging criterion in each aging oven. Remove all of the test specimens after a selected interval of time. (See 10.6.) Select the test specimens needed for the test at random. Return the remaining samples to the aging oven and repeat the process after each succeeding time interval (aging period).

10.6 Suggested total exposure times with associated test temperatures are given in Table 1. Initially, at least seven, evenly-spaced, test intervals at each test temperature are usually needed to provide sufficient data for the thermal life curves. (It is wise to provide sufficient specimens for ten intervals.) It is most important to adequately define the later portion of the thermal life curve. With experience, it is possible that fewer test specimens and time intervals will be needed. At the start, place only about half of the test specimens in the aging oven. Then use a relatively long, initial aging period. The test results after this initial aging period can provide guidance for subsequent time intervals for the remaining specimens in the oven. Then place the so-far, unaged specimens in the oven or withhold for an even longer period as suggested by the test results.

11. Dielectric Strength

11.1 *Apparatus:*

11.1.1 A testing device shall be employed whereby the test specimen is clamped under pressure between elastomeric gaskets to prevent flashover during the measurement. A suitable apparatus and details of the electrode assembly used in this apparatus are illustrated in Fig. 1.

11.1.2 The test assembly shall consist of an upper electrode holder, *2*, which is stationary, and a movable lower electrode holder, *6*. Each holder shall contain a ~~19-mm~~19 mm (3⁄4~~-in.)~~ in.) diameter electrode, *11*, with edges rounded to a radius of 3.18 mm (1⁄8 ~~in.).~~ in.). An elastomeric gasket, *12*, shall surround each electrode, allowing approximately ~~1.59-mm~~1.59 mm (1⁄16~~-in.)~~ in.) circumferential clearance between the gasket and the electrode. The specimen, *5*, shall be placed between the electrodes, which shall be spring-loaded, *10*, to provide ~~2.22-N~~2.22 N (1⁄2~~-lbf)~~ lbf) electrode pressure. Application of compressed air, controlled by a regulator, *9*, to the air cylinder, *8*, causes the lower electrode assembly to move upward against the specimen. The specimen is thus sealed between the holders by the elastomeric gaskets.

11.1.3 The holders shall be constructed from suitable electrical insulating materials.

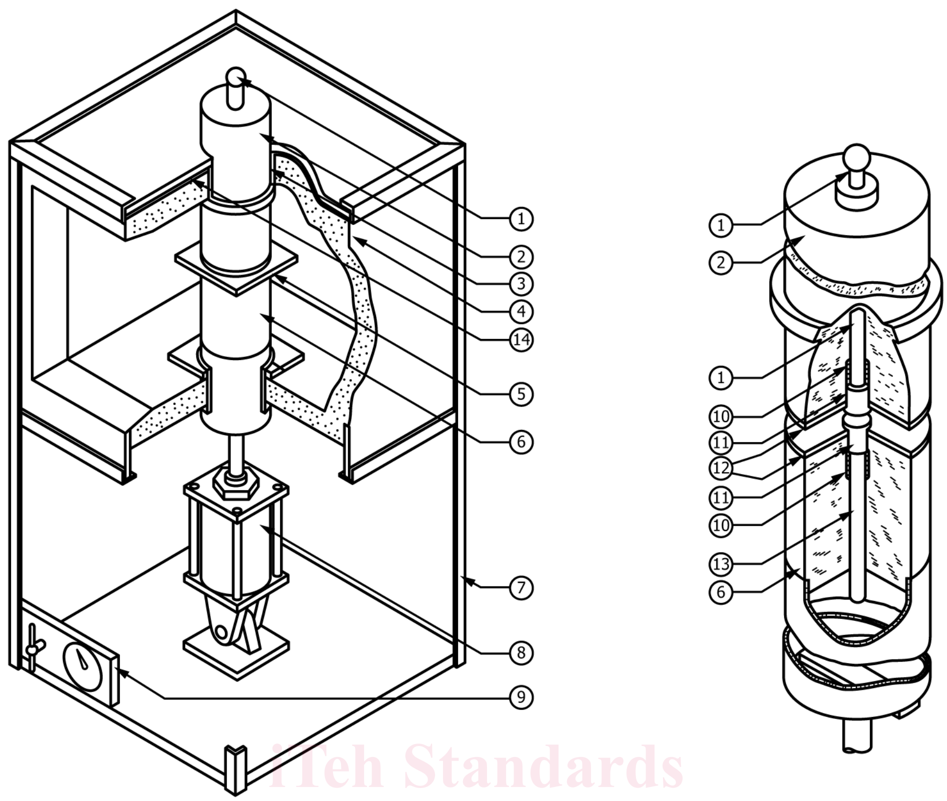
NOTE 1—Polyethylene ~~is suggested~~or polypropylene is used for room-temperature tests. Ceramic or silicone-glass are ~~optional~~ materials for use for elevated-temperature tests.

11.1.4 The gaskets shall be made from sheets of uncured silicone rubber of the highest track resistance available. These shall be molded in place between the holders under pressure and cured by application of heat.

11.1.5 The apparatus shall be so constructed that the bearing pressure is transmitted to an angle iron frame, *7*, by means of a bearing ring, *3*, and a top plate, *14*. Sheet metal, *4*, or metal lath shall be used to protect the operator from high voltage.

NOTE 2—The construction described allows placing the electrodes inside a standard oven for tests at elevated temperature if desired. The oven wall replaces the metal guard, *4*. The only modification to the oven that is required is cutting holes through the top and bottom for the electrode holders.

11.1.6 The electrode connecting rods, *1* and *13*, shall be tapped into the electrodes for ease of disassembly when it is necessary to clean the electrodes by machining.



1. Upper Electrode Connecting Rod—With Sphere Top
2. Upper Electrode Holder
3. Bearing Ring
4. Grounded Shield
5. Test Specimen
6. Movable Lower Electrode Holder
7. Skeleton Frame
8. Air Cylinder
9. Air Regulator
10. Spring for Loading Electrode
11. Cylinder Electrode
12. Elastomeric Gasket
13. Lower Electrode Connecting Rod
14. Top Plate (Bearing Plate)

FIG. 1 Test Assembly, Dielectric Strength Transverse-Air-Rigid Specimen

11.1.7 The dimensions of the holders and clearance distances are determined by the highest voltage that is desired. A practical working assembly used up to 60 kV has the following dimensions:

11.1.7.1 The holders and gaskets are 120.7 mm (4¾ in.) in diameter.

11.1.7.2 The electrodes are mounted inside an oven, the inside dimensions of which are ~~381 by 356 by 292 mm (15 by 14~~381 mm by 356 mm by 292 mm (15 in. by 14 in. by 11½ in.).

11.1.7.3 The closest air-gap distance from the holder insulation to the ground inside the oven is 127 mm (5 in.).

11.1.7.4 The closest air-gap distance from the sphere attached to the high-voltage electrode connecting rod to a ground is 254 mm (10 in.).

11.2 *Test Specimens:*

11.2.1 The test specimens shall be ~~152-mm (6-in.)~~152 mm (6 in.) squares cut from nominal ~~1.58-mm~~1.58 mm (1⁄16-in.) thick sheets, or shall be ~~152-mm~~152 mm diameter disks molded to a nominal 1.58 mm thickness.

11.2.2 Five or more specimens per exposure interval shall be used for each temperature as selected in accordance with Section 9.

11.2.3 Screen all specimens by applying ~~12 000 V for 1 min.~~ 12 000 V for 1 min. Specimens that fail the screening test shall be discarded.

11.3 *Procedure:*

11.3.1 Test for electric strength in accordance with Methods D149.

11.3.2 Obtain the thickness of each test specimen at or near its center and record.

11.3.3 Condition five or more specimens for ~~48 h~~ 48 h in the Standard Laboratory Atmosphere ~~(23~~(23 °C ± ~~1.1°C, 50~~1.1 °C, 50 % ± 10 % relative humidity).

11.3.4 Measure the breakdown voltage of each of five or more specimens at room temperature, using the pressure electrodes, by applying voltage at the rate of 0.5 kV/s. Calculate and record the electric strength in kV/mm (V/mil) (breakdown voltage divided by thickness in ~~millimetres~~millimeters or mils). ~~*Warning,*~~**Warning—***This test involves the use of high voltage. (See Section 4.)* ~~this test involves the use of high voltage. (See Section 4.)~~

11.3.5 Place approximately 50 specimens, or ten times the number of specimens used for each exposure interval, in the aging oven maintained at the selected temperature. At the end of the first exposure interval, remove five or more specimens and allow to cool for 2 h in the Standard Laboratory Atmosphere.

11.3.6 Test the specimens as in 11.3.4.

11.3.7 Remove the same number of specimens again at the end of another exposure interval; allow to cool for 2 h as in 11.3.5.

11.3.8 Test the specimens again as in 11.3.4.

11.3.9 Repeat until all specimens are tested or until it is judged that dielectric strength has reached a practical minimum value. As the data are collected it is acceptable to indicate that specimens need not be tested at the end of such planned exposure interval but rather after two or more of the planned intervals. Make any adjustment that is deemed necessary to obtain the degradation rate.

11.3.10 Plot results with dielectric strength as ordinate and total elevated temperature aging time as a log abscissa.

12. Flexural Strength

12.1 *Apparatus*—A testing machine, loading nose, and supports conforming to the requirements of Test Methods D790.

12.2 *Test Specimen:*

12.2.1 The test specimen shall be ~~76 by 25 by 3 mm (3 by 1~~76 mm by 25 mm by 3 mm (3 in. by 1 in. by ⅛ in.) in nominal thickness.

12.2.2 Specimens obtained from laminated plastics shall all be cut from the same direction of the sheet, lengthwise or crosswise. Where the direction cannot easily be determined, preliminary room-temperature tests shall be made. The direction exhibiting the greater flexural strength shall be considered the lengthwise direction. This corresponds to the warp direction of woven fabrics or to the machine direction for papers.

12.2.3 Use five or more specimens per exposure period for each temperature as selected in accordance with Section 10.

12.3 *Procedure*—Measure flexural strength flatwise in accordance with Test Method D229. Load the specimen on a ~~50-mm (2-in.)~~50 mm (2 in.) span.

12.3.1 Obtain the thickness of each test specimen and record.

12.3.2 Obtain the flexural strength of each of five or more specimens in accordance with Test Method D229 and record.