Designation: D 2304 – 97

An American National Standard

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

This standard is issued under the fixed designation D 2304; 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, this test method may also be used for some thin sheet (flexible) materials, which become rigid with thermal aging, but is not intended to replace Test Method D 1830 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 *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.* A specific warning statement is given in Note 3.

2. Referenced Documents

2.1 *ASTM Standards:*

D 149 Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials at Commercial Power Frequencies[3]

D 229 Test Methods for Rigid Sheet and Plate Materials Used for Electrical Insulation[3]

D 570 Test Method for Water Absorption of Plastics[4]

D 790 Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials[4]

D 1830 Test Method for Thermal Endurance of Flexible Sheet Materials Used for Electrical Insulation by the Curved Electrode Method[3]

D 5423 Specification for Forced-Convection Laboratory Ovens for Evaluation of Electrical Insulation[5]

2.2 *IEEE:*[6]

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

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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.

[3] *Annual Book of ASTM Standards*, Vol 10.01.

[4] *Annual Book of ASTM Standards*, Vol 08.01.

[5] *Annual Book of ASTM Standards*, Vol 10.02.

[6] Available from the Institute of Electrical and Electronics Engineers, 345 East 47th St., New York, NY 10017.

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 and minimum use thickness of 0.5 mm (0.02 in.). It is generally used as terminal boards, spacers, coil forms, voltage barriers, and circuit boards.

4. Summary of Test Method

4.1 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 at the highest aging temperature and 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. (Different values for the thermal index of a material may be obtained with different aging criteria.)

5. Significance and Use

5.1 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 should directly or indirectly represent functional needs in application. For example, a change in dielectric strength may be of direct, functional importance. However, more often a decrease in dielectric strength may indirectly indicate the development of undesirable cracking (embrittlement). A decrease in flexural strength may be of direct importance in some applications, but may also indirectly indicate a susceptibility to failure in vibration. Often two or more criteria of failure should be used; for example, dielectric strength and flexural strength.

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

5.3 For some applications, the aging criteria in this test method may 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, may serve better. The procedures in this test method may be used with such aging criteria. It is important to consider both the nature of the material and its application. For example, tensile strength may be a poor choice for glass-fiber reinforced laminates, because the glass fiber may maintain the tensile strength even when the associated resin is badly deteriorated. In this case, flexural strength is a better criterion of thermal aging.

5.4 When dictated by the needs of the application, an aging atmosphere other than air may be needed and used. For example, thermal aging can be conducted in an oxygen-free, nitrogen atmosphere.

6. End Point

6.1 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 could be 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).

6.2 Experience has shown that the choice of an end point can affect the comparative thermal life. A choice of end points should, therefore, be 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.

6.3 The specification for each material should state the end point to be used.

7. Aging Ovens

7.1 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 increase in exposure temperature.

7.2 Use aging ovens that conform to the requirements of Type I of Specification D 5423.

8. Test Specimen

8.1 The accuracy of the test results depends significantly upon the number of specimens exposed at each temperature

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	...	...	...	...

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 should be used at each exposure temperature. A separate group of test specimens is required for each exposure period.

8.2 The rate of deterioration may 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

9. Oven Aging (Thermal Exposure)

9.1 Factors such as moisture, chemical contamination, and mechanical stress or vibration usually do not in themselves cause failure, but are factors that may 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 method.

9.2 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. It is recognized that this table may be revised as a result of experience. Either the time or the temperature may be adjusted to make the best use of available oven facilities.

9.3 Age at a minimum of three and preferably four temperatures. Choose the lowest temperature to be less than 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, the aging temperatures should differ from each other by at least 20°C.

9.4 The selection of the appropriate aging temperatures for an unknown material may require a short exploratory test performed at the highest likely aging temperature. Results from thermal aging tests for a material with similar composition may provide clues for an appropriate selection of the first exploratory temperature. The chemical composition of the material to be tested, if known, may 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 9.3.)

9.5 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 9.6.) 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).

9.6 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, fewer test specimens and time intervals may 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.

10. Dielectric Strength

10.1 *Apparatus*:

10.1.1 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.

10.1.2 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 (¾-in.) diameter electrode, *11*, with edges rounded to a radius of 3.18 mm (⅛ in.). An elastomeric gasket, *12*, shall surround each electrode, allowing approximately 1.59-mm (1⁄16-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 (½-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.

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

NOTE 1—Polyethylene is suggested for room-temperature tests. Ceramic or silicone-glass may be used for elevated-temperature tests.

10.1.4 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.

10.1.5 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.

10.1.6 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.

10.1.7 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:

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

10.1.7.2 The electrodes are mounted inside an oven, the