An American National Standard

Standard Test Method for Thermal Failure of Solid Electrical Insulating Materials Under Electric Stress[1]

This standard is issued under the fixed designation D 3151; 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 covers the determination of the thermal failure of solid electrical insulating materials subjected to electric stress at commercial power frequencies. This test method has been developed for testing materials such as certain glasses and ceramics, that exhibit large increases in dielectric loss with increasing temperature.

1.2 *This standard does not purport to address all of the safety problems, 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 hazard statement is given in 10.1.

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[2]

D 374 Test Methods for Thickness of Solid Electrical Insulation[2]

D 1711 Terminology Relating to Electrical Insulation[2]

E 145 Specification for Gravity-Convection and Forced-Ventilation Ovens[3]

2.2 *Other Standards:*

IEEE Standard No. 4 Measurements of Voltage in Dielectric Tests[4]

3. Terminology

3.1 *Definition:*

3.1.1 *dielectric breakdown voltage*—see Terminology D 1711.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *thermal dielectric breakdown, n*—an increase in the dissipation factor or conductance in the test material which leads to failure by thermal runaway. The time to failure and the voltage stress at which thermal breakdown occurs is influenced by the ambient test temperature, the test voltage, the dimensions of the test specimen, the specific heat of the material, and its thermal conductivity.

3.2.2 *thermal dielectric breakdown voltage, n*—the voltage at which thermal dielectric breakdown takes place at a specified ambient temperature and thermal transfer condition.

3.2.3 *thermal runaway, n*—a mode of response exhibited by certain materials which, when subjected to electric stress exceeding a critical value, undergo a rise in temperature which itself increases the conductance of the material, further increasing the temperature, and so on in a self-escalating manner.

4. Significance and Use

4.1 This test method is intended to supplement the standard dielectric strength test procedure (Test Method D 149) for tests at elevated temperatures, particularly of glasses and ceramics. The method determines at elevated temperature the potential difference at which the current becomes so great due to increased conductance that dielectric heating causes the temperature in the material to rise and ultimately cause thermal electric breakdown to occur.

4.2 This test method is intended for use as a control and acceptance test. It may be used also in the partial evaluation of materials for specific end uses and as a means for detecting changes in materials due to specific deteriorating causes. A more complete discussion of the significance of thermal dielectric breakdown tests is given in Annex A1.

5. Apparatus

5.1 *High-Voltage Test Equipment*—Suitable equipment is described in Test Method D 149. The transformer rating should be adequate to maintain a sine wave at full-load current. Higher ratings than specified in Test Method D 149 are usually required.

5.2 *Voltmeter*—The voltage shall be measured in accordance with IEEE Standard No. 4. The response time of the voltmeter shall be such that its time lag does not introduce an

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

[3] *Annual Book of ASTM Standards*, Vol 14.02.

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

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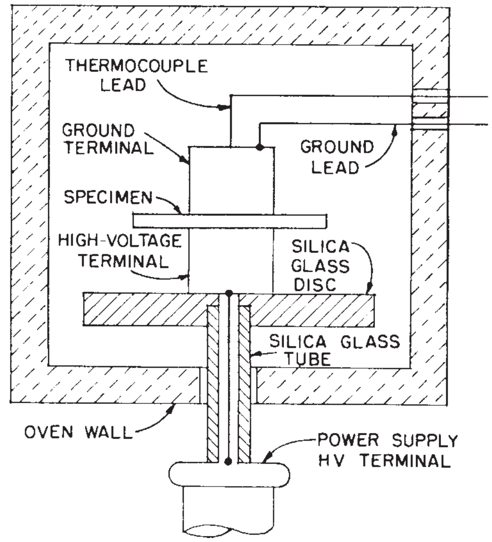

FIG. 1 General Arrangement in Test Chamber

error greater than 1% of full scale at the rate of rise used. The overall accuracy of the voltmeter and the voltage-measuring device used shall be such that the measurement error will not exceed 5%.

5.3 *Test Area*, containing the test chamber and high-voltage transformer shall be contained in a suitably grounded metal enclosure with a door provided with an interlock that interrupts the high voltage when opened.

5.4 *Test Chamber*:

5.4.1 The test chamber shall consist of an electrically heated furnace and an auxiliary temperature controller. A high-temperature gravity-convection oven with controller conforming to Specification E 145, Type 1, is suitable.

5.4.2 The size of the chamber shall be such that the highest test voltage anticipated, when applied to the test electrodes, will not flash over to the walls of the chamber at the highest temperature.

5.4.3 The chamber shall be provided with holes for three leads. A ceramic or fused-silica glass tube capable of withstanding the anticipated test voltage shall be inserted through one hole in the floor. The high-voltage lead shall be brought through this insulating tube. The ground lead and the thermocouple lead shall be brought through holes in the walls.

NOTE 1—Some investigators have found that a conductive coating on the inside surface of the insulating tube reduces corona.

5.4.4 A ceramic or fused-silica glass disk with a hole for the insulating tube of 5.4.3 to fit through should be placed at the bottom of the test chamber to prevent the high-voltage (bottom) electrode from shorting to the bottom of the chamber.

NOTE 2—Unless the disk fits the tube very closely, or is cemented to it, voltage breakdown may take place along the interface between the disk and the tube. For this reason, it may be necessary in some cases to use a one-piece insulator with an integral flange, or other appropriate shape to prevent breakdown in this location.

5.4.5 The glass tube and disk should be fastened to supports outside the furnace and should not touch the inside walls or other parts of the furnace.

5.4.6 Fig. 1 shows the general arrangment of the items cited in 5.4.3-5.4.5.

5.5 *Temperature Recorder*—Temperature of the specimen shall be measured with a No. 40 Awg (0.080-mm) Chromel-Alumel thermocouple. The thermocouple shall be connected to an adjustable-zero, multirange temperature recorder.

6. Surrounding Medium

6.1 In general it is preferable to test materials in the medium in which they are to be used. However in this test the surrounding medium is usually restricted to air or other gas or liquid that is stable at the test temperature.

7. Electrodes

7.1 The specimens shall have circular gold electrodes 31.75 $\pm$ 3.05 mm (1.25 $\pm$ 0.12 in.) in diameter applied to the center of each face. The gold may be applied with a brush or silk screen, and then fired in a furnace.[5]

7.2 Electrical contact to the gold electrodes on the specimen shall be made by means of two gold-plated hollow stainless steel cylinders having the same diameter as the gold electrodes as shown in Fig. 2.

7.3 The high-voltage connection shall be made to the bottom electrode. The top electrode shall be grounded.

8. Test Specimens

8.1 The test specimens shall be representative of the materials to be tested. Sufficient material shall be available to permit making ten tests.

[5] Gold electrodes that have been found satisfactory for this purpose when applied in accordance with the manufacturer's recommendations are:

(1) Liquid Bright Gold No. MM, Engelhard Industries, Inc., Hanovia Liquid Gold Div., East Newark, NJ and

(2) Vacuum-evaporated gold with suitable masks during application. (**Caution**—Significant errors may be produced if the thermocouple removes electrode material.)

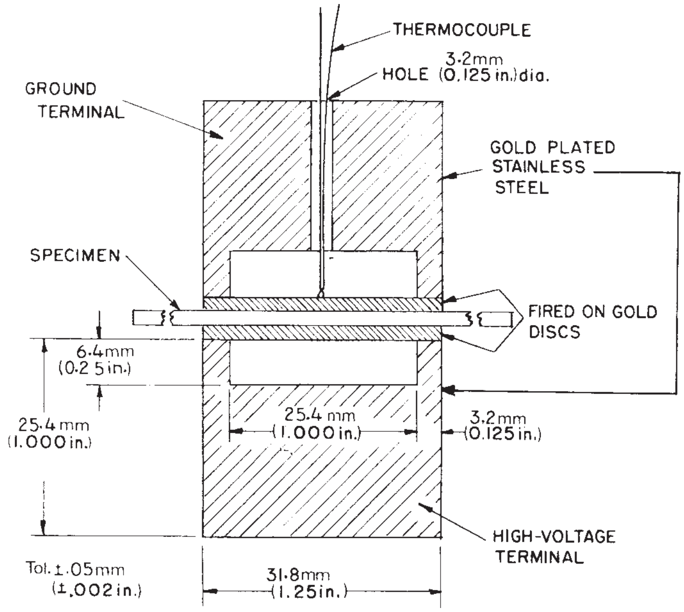

FIG. 2 Electrodes and Terminal Details

8.2 The test specimens shall be in the form of disks 2.0 ± 0.2-mm (0.078 ± 0.008-in.) having a diameter of 76 to 102 mm (3 to 4 in.). If there is a problem with surface flashover, larger diameter specimens may be used. If larger diameter specimens are used, report the diameter of the test specimen.

8.3 Apply electrodes to specimens as described in 7.3.

9. Thickness Measurement

9.1 Use the measured thickness of the test specimen for calculating the dielectric strength.

9.2 Unless otherwise specified, measure the thickness prior to applying the gold electrodes, at a temperature of 23 ± 3°C in accordance with Test Methods D 374.

10. Procedure

10.1 **Warning—** *Lethal voltages may be present during this test. It is essential that the test apparatus, and all associated equipment that may be electrically connected to it be properly designed and installed for safe operation. Solidly ground all electrically conductive parts that any person might come into contact with during the test. Provide means for use at the completion of any test to ground any parts which: were at high voltage during the test; may have acquired an induced charge during the test; may retain a charge even after disconnection of the voltage source. Thoroughly instruct all operators in the proper way to conduct the tests safely. When making high voltage tests, particularly in compressed gas or in oil, the energy released at breakdown may 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.*

10.2 Insert the test specimen, with the applied gold electrodes, between the the two cylindrical electrodes so that they contact the circumference of the gold electrodes. Place the assembly in the furnace on the fused silica disk and connect the high-voltage lead to the lower electrode. Connect the ground lead to the upper electrode (see Fig. 1).

10.3 Insert the thermocouple junction through the hole in the upper stainless steel cylinder to make contact with the center of the upper gold disk on the specimen. Although the electrodes are shaped to maintain the specimen material within the gold electrode area at a uniform temperature, the measured specimen temperature will be the lowest at the center of the gold electrode area. Electrical continuity should be checked with an ohmmeter.

10.4 Increase the temperature of the furnace to the desired test temperature and allow the temperature of the furnace and the test specimen to stabilize.

10.5 When the furnace and the test specimen temperatures are stabilized, apply the test voltage. The recommended procedure is the short-time test method of Test Method D 149. Increase the voltage from zero at a rate of 500 ± 100 V/s until the desired test voltage is attained. Maintain the test voltage at the specified value and record the temperature rise of the specimen as a function of time.

10.6 At voltages below the breakdown voltage the temperature of the specimen, after the application of test voltage, will initially rise and then stabilize. After the temperature has stabilized, reduce the test voltage to zero and allow the specimen to cool to the furnace temperature.

10.7 Repeat this procedure using a higher test voltage. The temperature of the specimen should stabilize at a higher value than recorded for the previous run.

10.8 Repeat this procedure at successively higher test voltages until a voltage is reached where the temperature of the specimen does not stabilize but continues to rise. This voltage is considered to be the dielectric breakdown voltage of the specimen at the temperature of the furnace.

10.9 This procedure may be repeated at several furnace temperatures to obtain the dielectric strength of a material at different temperatures or to compare different materials at several temperatures.

11. Report

11.1 Unless otherwise specified, report the following information:

11.1.1 Test specimen material,

11.1.2 Test specimen dimensions,

11.1.3 Type of furnace used,

11.1.4 Furnace temperature,

11.1.5 Composition of the surrounding medium within the furnace,

11.1.6 Magnitude of each voltage step,

11.1.7 Time at each voltage step,

11.1.8 Specimen temperature at stabilization for each test voltage,

11.1.9 Dielectric breakdown voltage of each test specimen,

11.1.10 Location of each breakdown, and

11.1.11 Dielectric strength of each test specimen.

12. Precision and Bias

12.1 The precision of this test method has not been determined.

NOTE 3—Operators familiar with this test method estimate that the variation of the means of observations within a single laboratory is not expected to exceed 10 %.

12.2 A statement of bias cannot be made because of the absence of a standard reference material.

13. Keywords

13.1 electric stress; thermal dielectric breakdown; thermal dielectric breakdown voltage; thermal failure; thermal runaway

ANNEX

(Mandatory Information)

A1. DISCUSSION OF SIGNIFICANCE OF THERMAL DIELECTRIC BREAKDOWN TESTS

A1.1 The elevated-temperature dielectric strength of solid electrical insulating materials is an important factor in the design of equipment and devices using electrical energy in elevated-temperature environments. The ability of electrical insulation to isolate the electrical potential in a controlled manner is essential for proper performance.

A1.2 Voltage breakdown at elevated temperature is often a thermal phenomenon. In thermal breakdown, the dielectric losses cause the material to heat appreciably when voltage is applied. The failure voltage is determined by the heat balance between resistance heat input and heat loss by conduction, radiation, and convection. The failure voltage will be higher when there is good heat transfer away from the electrically stressed region of the specimen. This heating decreases the electrical resistance, which in turn causes greater heating. This sequence is repeated until either dielectric failure occurs, or if the voltage is below a critical value, a stabilized condition may exist at which the rate of heat input equals the rate of heat loss. The rate of heat loss depends upon electrode geometry, ambient gas and its pressure, and other factors.

A1.3 In the disruptive type of dielectric breakdown, the temperature of the material does not increase appreciably except in a very localized area. This type is usually associated with voids and defects in the material.

A1.4 The thermal failure voltage on the other hand, can be estimated from information on the loss index as a function of temperature, the thermal conductivity of the specimen, its geometry, and the thermal resistance external to the specimen. More details are given by Whitehead.[6]

A1.5 Since the breakdown voltage at elevated temperatures is dependent upon the specimen thickness and electrode diameter, it must be emphasized that, as in all dielectric strength measurements, the breakdown values obtained apply only to the particular test conditions and specimen configuration and should be used only to compare one material with another. The electrode system specified is designed to minimize the heat transfer away from the central portion of the electrically stressed specimen and will give a failure voltage nearer the minimum possible with this type of dielectric breakdown.

[6] Whitehead, S., *Dielectric Breakdown of Solids*, Oxford University Press, Amen House, London, E.C.4.

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