Designation: D 3755 – 97

An American National Standard

Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials Under Direct-Voltage Stress[1]

This standard is issued under the fixed designation D 3755; 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 dielectric breakdown voltage and dielectric strength of solid electrical insulating materials under direct-voltage stress.

1.2 Since some materials require special treatment, reference should also be made to ASTM specifications or to the test method directly applicable to the material to be tested. See Test Method D 149 for the determination of dielectric strength of electrical insulating materials at commercial power frequencies.

1.3 This test method is similar to IEC Publication 243-2. All procedures in this test method are included in IEC 243-2. Differences between this test method and IEC 243-2 are largely editorial.

1.4 *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.* Specific precaution statements are given in Section 7.

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 176 Test Methods for Solid Filling and Treating Compounds Used for Electrical Insulation[2]

D 877 Test Method for Dielectric Breakdown Voltage of Insulating Liquids Using Disk Electrodes[3]

D 1711 Terminology Relating to Electrical Insulation[2]

D 2436 Specification for Forced-Convection Laboratory Ovens for Electrical Insulation[2]

D 3487 Specification for Mineral Insulating Oil Used in Electrical Apparatus[3]

2.2 *ANSI Standard:*[4]

ANSI C68.1 Techniques for Dielectric Tests, IEEE Standard No. 4.

2.3 *IEC Standard:*

IEC 243-2 Methods of test for electric strength of solid insulating materials—Part 2: Additional requirements for tests using direct voltage[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *dielectric breakdown voltage*, *n*—Refer to Terminology D 1711.

3.1.2 *dielectric strength*, *n*—Refer to Terminology D 1711.

3.1.3 *flashover*, *n*—Refer to Terminology D 1711.

4. Summary of Test Method

4.1 The specimen, held in a properly designed electrode system, is electrically stressed by the application of an increasing direct voltage until internal breakdown occurs. The test voltage is applied at a uniform rate of increase. The direct voltage is obtained from a high-voltage supply of adequate current capacity and regulation, reasonably ripple-free, with facilities for measuring and controlling the output voltage.

5. Significance and Use

5.1 This test method is intended for use as a control and acceptance test for direct-voltage applications. It may be used also in the partial evaluation of material for specific end uses and as a means for detecting changes in material due to specific deteriorating causes.

5.2 Experience indicates that the breakdown value obtained with direct voltage usually will be approximately 2 to 4 times the rms value of the 60-Hz alternating-voltage breakdown.

5.3 For a nonhomogeneous test specimen, the distribution of voltage stress within the specimen is determined by impedance (largely capacitive) with alternating voltage. With an increasing direct voltage, the voltage distribution may be still

[1] This test method is under the jurisdiction of ASTM Committee D-9 on Electrical and Electronic Insulating Materials and is the direct responsibility of Subcommittee D09.12 on Electrical Tests.

Current edition approved March 10, 1997. Published March 1998. Originally published as D 3755 – 79. Last previous edition D 3755 – 86 (1995) $^{\epsilon 1}$.

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

[3] *Annual Book of ASTM Standards*, Vol 10.03.

[4] Available from American National Standards Institute, 11 West 42nd St., 13th Floor, New York, NY 10036.

largely capacitive, but depends partly on the rate of voltage increase. After steady application of direct voltage the voltage division across the test specimen is determined by resistance. The choice of direct or alternating voltage depends upon the purpose for which the breakdown test is to be used, and to some extent, on the intended application of the material.

5.4 A more complete discussion of the significance of dielectric breakdown tests is given in Appendix X1 of this method and of Test Method D 149. Those appendix sections of Test Method D 149 that refer to alternating voltage are not applicable to the direct-voltage method.

6. Apparatus

6.1 *Basic Direct-Voltage Power Supplies*, or dielectric test sets of various voltage ratings, that can operate with one of the two output terminals grounded, are commonly available commercially. Such apparatus customarily includes the necessary voltage-control, voltage-measuring, and circuitinterrupting equipment. A provision for retaining the breakdown voltage reading after breakdown is desirable.

6.1.1 For a direct voltage derived from a rectified and filtered power frequency source, ripple on the output voltage generally should be less than 1 %. The criterion is met if the time constant of the circuit is at least 0.4 s. The time constant is product of the filter capacitance plus the specimen capacitance in microfarads, and the specimen insulation resistance (in megohms) corresponding to the parallel combination of the voltmeter circuit resistance and the specimen resistance.

6.2 *Voltage Control*, that will enable the test voltage to be increased at a linear rate. Preference should be given to a variable-speed motor-driven voltage control over a manual control. The rate-of-rise of test voltage shall not vary more than ±20 % from the specified rate at any point.

6.3 *Voltmeter*, to measure the voltage directly applied to the electrode system. The response of the voltmeter shall be such that its time lag shall not introduce an error greater than 1 % of full scale at any 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 ±2 % of full scale and be in accordance with ANSI C68.1.

6.4 *Electrodes*:

6.4.1 For those cases when the insulating material is in the form of flat sheet or tape, or is of the nature of a semisolid (for example, grease potting material, etc.) the electrodes may be selected from those listed in Table 2 of Test Method D 149. The electrode contact pressure shall be adequate to obtain good electrical contact.

6.4.2 Where excellent electrode contact is considered important, use paint or vaporized metal electrodes. Such electrodes may also be used when specimen geometry prevents the use of rigid, solid metal electodes. The results obtained with painted or sprayed electrodes may not be comparable with those obtained using other types of electrodes.

6.5 *Test Chamber*—For tests under other than ambient conditions, the specimen must be placed in a suitable environmental chamber of adequate size. For tests at elevated temperatures, an oven that meets the requirements of Specification D 2436 may be convenient. The test chamber must be equipped with safety devices (Section 7).

6.6 *Ground Switch*—The power supply shall be equipped with a grounding switch that is gravity operated and designed to close in less than 0.5 s. The grounding switch shall connect the high-voltage output terminal of the power supply and ground terminal through a low resistance when the input supply power is removed or the test chamber door is opened.

7. Safety Precautions

7.1 **Warning**— *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. Solidly ground all electrically conductive parts which it is possible for a person to contact 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 or have the potential for acquiring an induced charge during the test or retaining a charge even after disconnection of the voltage source. Thoroughly instruct all operators as to the correct procedures for performing tests safely. 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.*

7.2 When a direct-voltage test has been applied to the test specimen, both the specimen and power supply can remain charged after the test voltage source has been de-energized. This may present a hazard to test personnel. Direct-voltage testing may be more hazardous than testing with alternating voltage, where the charge on the specimen is rapidly dissipated in the low-impedance winding of the test transformer after the test is de-energized.

7.3 The test specimen and high-voltage output of the power supply must be enclosed in a grounded metallic screen. Access to the test enclosure must be dependent upon prior grounding of the power supply and test specimen through a low resistance as referred to in 6.6.

7.4 A manual grounding stick must be used to completely discharge the test specimen and power supply after the test and prior to handling them. The grounding stick should be left in contact with the test specimen and high-voltage transformer terminals for as long as feasible.

7.5 **Warning**—Ozone is a physiologically hazardous gas at elevated concentrations. Levels of acceptable industrial exposure have been established by the American Conference of Government and Industrial Hygienists.[5] Ozone has a distinctive odor that is initially discernible at low concentrations, but temporary loss of the sense of smell can occur. It is likely to be present wherever voltages exist that are sufficient to cause partial or complete discharges in air or other atmospheres containing oxygen. When the odor of ozone is persistently present or when ozone generating conditions continue, the

[5] American Conference of Governmental Industrial Hygienists, Building D-7, 6500 Glenway Drive, Cincinnati, OH 45211.

concentration of ozone in the atmosphere should be measured using commercially available monitoring devices. Appropriate means, such as installation of exhaust vents, shall be taken to maintain ozone concentrations in working areas within acceptable levels.

8. Criteria of Breakdown

8.1 Dielectric breakdown is generally accompanied by an increase in current in the test circuit that may activate a sensing element such as a circuit breaker, a fuse, or current-sensing circuit. If sensitivity of the element is well coordinated with the characteristics of the test equipment and the material under test, its operation may be a positive indication of breakdown.

8.2 Failure of a circuit breaker to operate may not be a positive criterion of the absence of breakdown. A breaker may fail to trip because it is set for too great a current or because of malfunction. On the other hand, if the tripping circuit is set for too low a current, currents due to leakage or partial discharge (corona) may cause it to trip before breakdown voltage is reached.

8.3 Observe the specimen during the test to ascertain that tripping of the breaker or current-sensing circuit is not caused by flashover. When flashover is a problem, it will be necessary to provide for more creepage distance around the electrodes, to decrease specimen thickness, or to immerse the specimen in a liquid dielectric (Section 13).

8.4 Observation of actual rupture or decomposition is positive evidence of specimen breakdown. In test position, however, these physical evidences of breakdown may not be apparent. If breakdown is in question it is common practice to repeat the test on the same specimen. Breakdown is confirmed when reapplication of test voltage results in a substantially lower breakdown voltage.

9. Test Specimens

9.1 For a description of test specimens of materials and their preparation, refer to the ASTM methods applicable to the materials to be tested.

9.2 Provide specimens that are representative of the material to be tested. Prepare enough specimens to permit making five tests. In the preparation of test specimens from solid materials, take care that the surfaces in contact with the electrodes are parallel and as plane and smooth as the material permits.

9.3 *Thin Solid Materials (Sheets and Plates Less than 3 mm Thick)*—Prepare test specimens of sufficient area to prevent flashover under the conditions of test.

9.4 *Thick Solid Materials*—The breakdown of thick solid materials is generally so high that the specimen must be immersed in insulating fluid to prevent flashover and to minimize partial discharge. See Section 13. Other techniques which may be used to prevent flashover are:

9.4.1 The machining of a recess in the test specimen for an electrode.

9.4.2 The use of shrouds on the test specimen.

9.4.3 The application of a sealing apparatus under pressure to the upper and lower faces of the test specimen.

10. Thickness

10.1 The thickness used in computing the dielectric strength shall be the average thickness of the specimen measured as specified in the test method for the material involved. If not specified, the thickness measurement shall be made at room temperature of 25 ± 5°C.

10.2 If the material is laminar or known to vary in dielectric strength with orientation, such as caused by graininess, the specimen should be cut so that its thickness is in the direction of the electric field under use conditions.

10.3 When thin materials, such as laminates, are to be tested in the direction of their width or length, special procedures may be needed to avoid flashover, some of which are described in 9.4. Provisions for such tests may also be included in the methods for specific materials.

11. Number of Tests

11.1 Unless otherwise specified, test five specimens.

12. Conditioning

12.1 The dielectric strength of most insulating materials varies with temperature and humidity. Condition such materials in a suitably controlled chamber. For information concerning the conditioning treatment, refer to the particular method for a given material. Keep the test specimens in the chamber long enough to reach a uniform temperature and humidity before tests are started. It may be desirable to determine the dielectric behavior of a material over a range of temperature and humidity to which it is likely to be subjected in use. If conditioning is performed under conditions where condensation will occur, it may be desirable to wipe off the surface of the test specimen carefully immediately before testing, as this will generally tend to minimize flashover.

12.2 Since some materials require a long time to attain equilibrium at normal conditions of temperature and humidity specify conditioning when specimens are to be subjected to tests for evaluation of quality control and purchase specification requirements in order to obtain reproducible results.

13. Surrounding Medium

13.1 In general, it is preferable to test materials in the medium in which they are to be used, whether air, other gas, or an insulating liquid. Refer to the ASTM method applicable to the particular material to be tested to determine whether a medium is specified.

13.2 Where conditions of use are not well defined, test materials in air unless an excessive amount of material is required to prevent flashover or excessive burning of the surface. In that case, it is common practice to test the material under oil. Do not use liquid dielectrics as a surrounding medium for porous materials that are intended to be used in air, other gas, or vacuum. Limit direct comparison of test results to those made in the same medium.

13.3 When tests are to be made under oil, provide an oil bath of adequate size. Use a good grade of clean transformer oil or similar oil, in accordance with Specification D 3487 unless other oil is specified.

14. Procedure

14.1 Increase the voltage at a uniform rate from zero to breakdown. For a given material, refer to the applicable specification or test method for the rate. Use a rate of 500 V/s if applicable, and if not otherwise specified. Calculate the rate from measurements of time required to raise the voltage between two selected values. For a given material, refer to the applicable material specification or test method for the rate. Consider breakdown to have occurred only when the conditions of Section 8 have been met. Record the test voltage at breakdown.

14.2 Refer to Section 8 for criteria of breakdown.

14.3 Record the voltage at breakdown.

15. Report

15.1 Unless otherwise specified, report the following:

15.1.1 Average thickness of the specimen,

15.1.2 Breakdown voltage at each puncture,

15.1.3 Average, maximum, and minimum breakdown voltage for each specimen,

15.1.4 Average dielectric strength of the specimens,

15.1.5 Ambient temperature of test environment,

15.1.6 Ambient relative humidity in percent of test environment,

15.1.7 Conditioning,

15.1.8 Polarity and rate-of-rise of voltage,

15.1.9 Size, shape, and type of the electrodes, and

15.1.10 Surrounding medium.

16. Precision and Bias

16.1 The precision and bias of the test results will be dependent upon the materials tested and the conditions of test. Therefore, reference should be made to the applicable material test method.

17. Keywords

17.1 conditioning; creepage; criteria of breakdown; dielectric breakdown voltage; dielectric strength; direct voltage; direct voltage stress; electrodes; flashover; rupture; solid insulating materials; surrounding medium; voltage control; voltmeter

APPENDIX

(Nonmandatory Information)

X1. SIGNIFICANCE OF THE DIRECT VOLTAGE DIELECTRIC STRENGTH TEST

X1.1 Introduction

X1.1.1 A brief review of three postulated mechanisms of breakdown, namely: (*1*) the discharge or partial discharge mechanism, (*2*) the thermal mechanism, and (*3*) the intrinsic mechanism, as well as a discussion of the principal factors affecting tests on practical dielectrics, are given here to aid in interpreting the data. The breakdown mechanisms usually operate in combination rather than singly. The following discussion applies only to solid and semi-solid materials.

X1.2 Factors Affecting Direct Voltage Dielectric Breakdown

X1.2.1 With a steady direct voltage applied to the test specimen, the distribution of voltage within the specimen is a direct function of the insulation resistance of each component of the specimen. Higher voltage stresses occur in regions of relatively high volume resistivity, for example, across an air gap in series with a solid cavity or at the electrode edges. Even so, partial discharges (corona) are less likely to occur with direct voltage because such discharges are induced when the voltage changes rapidly, such as with alternating or impulse voltage.

X1.2.2 The dielectric loss, W (watts), in the specimen is calculated from the square of the direct voltage, V (volts), divided by the insulation resistance, R (ohms) $W = E^{2}/R$. The watts per unit volume is related to the possibility of thermal failure. Refer to the Appendix of Test Method D 149 for a description of thermal failure. The wattage loss is almost always much smaller on direct voltage than on alternating voltage so that thermal runaway breakdown is less likely to occur.

X1.2.3 Direct voltage breakdown is somewhat more sensitive than alternating voltage to material defects lying in the direction of the stress. Orientation of insulation defects will affect breakdown levels. Defects lying in the direction of the voltage stress will be more critical than those perpendicular to the stress.

X1.2.4 Since thermal breakdown and breakdown caused by electrical discharges (see Test Method D 149) are less important in direct voltage breakdown than in alternating voltage breakdown, the direct voltage breakdown is more likely to approach the theoretical maximum breakdown voltage.

X1.3 Nature of Electrical Insulating Materials

X1.3.1 Solid commercial electrical insulating materials are generally nonhomogeneous and may contain dielectric defects of various kinds. Dielectric breakdown often occurs in an area of the test specimen other than that where the field intensity is greatest and sometimes in an area remote from the material directly between the electrodes. Weak spots within the volume under stress sometimes determine the test results.

X1.4 Influence of Test and Specimen Conditions

X1.4.1 *Electrodes*— In general, the breakdown voltage will tend to decrease with increasing electrode area, this area effect being more pronounced with thin test specimens. Test results are also affected by the electrode geometry. Results may be affected also by the material from which the electrodes are constructed, since the thermal and discharge mechanism may be influenced by the thermal conductivity and the work function, respectively, of the electrode material. Generally speaking, the effect of the electrode material is difficult to establish because of the scatter of experimental data.

X1.4.2 *Specimen Thickness*—The dielectric strength of solid commercial electrical insulating materials is greatly dependent upon the specimen thickness. Experience has shown that for solid and semi-solid materials, the dielectric strength varies inversely as a fractional power of the specimen thickness, and there is a substantial amount of evidence that for relatively homogeneous solids, the dielectric strength varies approximately as the reciprocal of the square root of the thickness. For solids that can be melted and poured to solidify between fixed electrodes, the effect of electrode separation is less clearly defined. Since the electrode separation can be fixed at will it is customary to perform dielectric strength tests on fusible solids, with electrodes having a standardized fixed spacing. Since the dielectric strength is so dependent upon thickness it is meaningless to report dielectric strength data for a material without stating the thickness of the test specimens used.

X1.4.3 *Temperature*— The temperature of the test specimen and its surrounding medium influence the dielectric strength, although for most materials small variations of ambient temperature may have a negligible effect. In general, the dielectric strength will decrease with increasing temperatures, but the extent to which this is true depends upon the material under test. When it is known that a material will be required to function at other than normal room temperature, it is essential that the dielectric strength-temperature relationship for the material be determined over the range of expected operating temperatures.

X1.4.4 *Time*—Test results will be influenced, to some extent, by the rate of voltage application, but to a lesser degree than alternating voltage breakdown. As the direct voltage changes, the distribution of electrical charges in and on the surface of the test specimen also change with time. In some cases, an unequal distribution of electrical charges on the surface may cause an anomalous surface flashover.

X1.4.5 *Wave Form*—In general, the dielectric strength is influenced by the wave form of the applied voltage. Within the limits specified in this method the influence of wave form is not significant.

X1.4.6 *Surrounding Medium*—The surrounding medium can affect the heat transfer rate, external discharges, the field uniformity, thereby greatly influencing the test results. Results in one medium cannot be compared with those in a different medium.

X1.4.7 *Relative Humidity*—The relative humidity influences the dielectric strength to the extent that moisture absorbed by, or on the surface of, the material under test affects the dielectric loss and surface conductivity. Hence, its importance will depend to a large extent upon the nature of the material being tested. However, even materials that absorb little or no moisture may be affected because of greatly increased chemical effects of discharge in the presence of moisture. Except in cases where the effect of exposure on dielectric strength is being investigated, it is customary to control or limit the relative humidity effects by standard conditioning procedures.

X1.5 Evaluation

X1.5.1 A fundamental requirement of the insulation in electrical apparatus is that it withstand the voltage imposed on it in service. Therefore there is a great need for a test to evaluate the performance of particular materials at high voltage stress. The dielectric breakdown voltage test represents a convenient preliminary test to determine whether a material merits further consideration, but it falls short of a complete evaluation in two important respects. First, the condition of a material as installed in apparatus is much different from its condition in this test, particularly with regard to the configuration of the electric field and the area of material exposed to it, partial discharge (corona), mechanical stress, ambient medium, and association with other materials. Second, in service there are deteriorating influences, heat, mechanical stress, partial discharge (corona) and its products, contaminants, etc., which may reduce the breakdown voltage far below its value as originally installed. Some of these effects can be incorporated in laboratory tests, and a better estimate of the material will result but the final consideration must always be that of the performance of the material in actual service.

X1.5.2 The dielectric breakdown test may be used as a material inspection or quality control test, as a means of inferring other conditions such as variability, or to indicate deteriorating processes such as thermal aging. In these uses of the test it is the relative value of the breakdown voltage that is important rather than the absolute value.