



# Standard Test Methods for Relative Permittivity And Dissipation Factor of Expanded Cellular Polymers Used For Electrical Insulation<sup>1</sup>

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## INTRODUCTION

Although fundamentally similar to test methods used for solid electrical insulating materials in sheet or plate form, certain modifications in the procedures and measurement techniques are necessary for the proper determination of the relative permittivities and dissipation factors of foamed or expanded cellular polymers. This is occasioned by the fact that in many, if not most, instances expanded cellular materials have surfaces that preclude the use of conventional electrodes such as metal foil attached by petrolatum and similar adhesives, or conducting silver paint applied by brushing or spraying. Furthermore, it is generally true that slabs or plates of expanded cellular materials are available only in substantially greater thicknesses than those commonly used for test specimens of solid insulation.

## 1. Scope

1.1 These test methods cover procedures for determining the relative permittivities and dissipation factor of flat sheets or slabs of expanded cellular polymers of both the rigid and flexible types, at frequencies from 60 Hz to 100 MHz. Provision is made for measurements on specimens up to 50 mm (2 in.) in thickness, but it is recommended that specimens greater than 25 mm (1 in.) in thickness shall be tested at frequencies up to a maximum of only about 1 MHz.

1.2 *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 150 Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulating Materials<sup>2</sup>

D 374 Test Methods for Thickness of Solid Electrical Insulation<sup>2</sup>

D 1056 Specification for Flexible Cellular Materials

Sponge or Expanded Rubber<sup>3</sup>

D 1711 Terminology Relating to Electrical Insulating Materials<sup>2</sup>

## 3. Terminology

3.1 For definitions of relative permittivity, dissipation factor, and loss index, refer to Test Methods D 150 or Terminology D 1711.

## 4. Significance and Use

### 4.1 Relative Permittivity:

4.1.1 Because a relatively large proportion of their volumes are composed of more or less uniformly distributed, isolated or interconnected gas-filled cells, foamed or expanded cellular polymers always have lower relative permittivities, at a given frequency and temperature, than the solid base resins from which they are prepared.

4.1.2 The relative permittivities of expanded cellular polymers are important because they determine the increase in capacitance between conductors, or between conductors and ground, that will result when a circuit or component is encapsulated in such a material, over their corresponding values before encapsulation (when air is the surrounding medium). Likewise, the relative permittivities of an expanded cellular polymer may serve as a measure of the decrease of such capacitances caused by substitution of the expanded material for a solid encapsulating compound or resin of known relative permittivity.

<sup>1</sup> These test methods are under the jurisdiction of ASTM Committee D-9 on Electrical and Electronic Insulating Materials and are the direct responsibility of Subcommittee D 09.12 on Electrical Tests.

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<sup>2</sup> Annual Book of ASTM Standards, Vol 10.01.

<sup>3</sup> Annual Book of ASTM Standards, Vol 09.02.

4.1.3 In transmission lines, such as coaxial cable, television lead-in cables, etc., the reduction of relative permittivity of an expanded material from its value in the original solid state has significant usefulness in design, since the capacitance per foot of cable, and such cable characteristics as velocity of propagation and characteristic impedance are all dependent upon the relative permittivity of the insulating material.

4.1.4 In wave guides, radomes, dielectric lenses, etc., for use at radio frequencies, if the cellular polymer is nonmagnetic, the relative permittivity (usually in combination with the dissipation factor) determines such transmission characteristics as velocity of propagation, attenuation distance, decibel loss per meter, phase factor, complex index of refraction, index of absorption, and dielectric conductivity.<sup>4</sup>

4.1.5 The relative permittivity determination may serve as a production control test for batch-to-batch uniformity of a given expanded cellular polymer. For expanded cellular nonpolar polymers (polyethylene, polystyrene, etc.), the relative permittivity measurement may constitute a useful control test on the density of the product.

NOTE 1—For useful information concerning the relationship of the relative permittivity of an expanded cellular material to its density and to the relative permittivity of the solid constituent, see Appendix X1.

4.2 Dissipation Factor and Loss Index:

4.2.1 The loss index of an expanded cellular polymer is a measure of the ac power loss in the material. When two materials have the same relative permittivities, their relative dielectric losses per unit volume at a given frequency and applied voltage gradient are directly indicated by their respective dissipation factors.

4.2.2 Since the dielectric loss in an insulating material results in the generation of heat, with a subsequent rise in temperature of the material, it is desirable in most cases that these losses be as low as possible. This is important not only from the standpoint of the overall efficiency of an electrical system but also because the increased temperature generally causes significant changes in both the relative permittivity and loss and thereby may contribute to instability of operation, particularly in radio-frequency circuits.

4.2.3 The dielectric loss, as measured by the dissipation factor and loss index, may serve as a quality control criterion and as a means of determining batch-to-batch uniformity of a product. It is also an excellent means of measuring the effects of weathering, aging, and absorption of moisture by the expanded cellular polymer, these influences generally resulting in substantial increases in the dielectric loss index.

4.2.4 The dissipation factor (usually in combination with the relative permittivity) is useful in estimating the contribution of the dielectric loss to the total attenuation in coaxial cables, and in calculations of the transmission characteristics of radomes, dielectric lenses, and related devices, as indicated in 4.1.4.

5. Apparatus

5.1 *Electrical Measurement Apparatus*, consisting of suitable bridge and resonant-circuit equipment having characteristics as prescribed in Test Methods D 150. Provision shall be made for the performance of relative permittivity and dissipation factor tests at any desired frequency in the range between 60 Hz and 100 MHz.

6. Electrodes

6.1 Expanded cellular polymers, in general, do not have surfaces suitable for attachment of conventional metal foil or conducting paint electrodes, so that prefabricated rigid metal plate electrodes must usually be employed for relative permittivity and dissipation factor tests. Such electrode systems may be of either the direct contact type or the noncontacting type.

6.2 *Direct-Contact Electrode Systems*— Direct-contact type electrodes may be one of the following:

6.2.1 A calibrated micrometer electrode system of the Hartshorn-Ward type, shown in Fig. 1 (Fig. 10 of Test Methods D 150), is particularly useful for samples 50 mm (2 in.) in diameter and up to about 6.35 mm (0.25 in.) thick. This system may be used at any frequency up to 100 MHz. Specimens are lightly clamped and in contact with both electrodes. Care must be observed to avoid compressing or crushing the material.

6.2.2 Two rigid plate electrodes with a single sheet specimen between and in contact with them may be used with the specimen the same size as the electrodes (see Table 1). It may be desirable to enclose this system in a metal box for shielding. A wide range of specimen sizes and thicknesses may be handled by various modifications of this system. However, the upper frequency limit is relatively low for larger thick specimens.

6.2.3 A three-plate electrode system with a double specimen arranged in a sandwich form may be used and is recommended for large sheets of thick materials for tests at relatively low frequencies. The two specimens should be of nearly the same thickness. The two outer plates are connected together and to ground or to the low side of the measuring apparatus. The third (middle) electrode serves as the high side. The system has the advantage of being practically self-shielding.

6.3 *Noncontacting Electrode Systems (“Air Gap” Methods):*

6.3.1 A calibrated micrometer electrode system of the Hartshorn-Ward type, shown in Fig. 1 may be used, with the

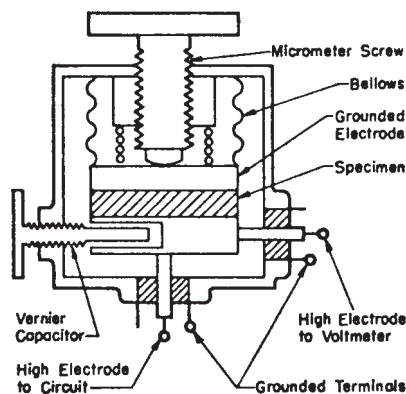


FIG. 1 Micrometer Electrode System

<sup>4</sup> For details see von Hippel, A. R., *Dielectrics and Waves*, Part I, John Wiley & Sons, Inc., New York, NY 1954, Ch. 9, pp. 26–37.

**TABLE 1 Suggested Specimen and Electrode Sizes and Maximum Test Frequencies for Relative Permittivity and Dissipation Factor Measurements on Expanded Cellular Plastic Sheets of Various Thicknesses up to 50 mm (2 in.).**

| Thickness of Specimen Approximate |      | Diameter of Round, or Length of Side of Square Specimens and Electrodes |          |             |     | Test Frequency, max, Approximate MHz |                      |
|-----------------------------------|------|---|----------|-------------|-----|--------------------------------------|----------------------|
| mm                                | in.  | Recommended   |          | Permissible |     | Recommended                          | Permissible          |
|                                   |      | mm  | in.      | mm          | in. |                                      |                      |
| Up to 6.35                        | 0.25 | 101.6   | 4.0      | 50.8        | 2.0 | 10.0                                 | 50: 100 <sup>A</sup> |
| 12.7                              | 0.50 | 152.4   | 6.0      | 50.8        | 2.0 | 1.0                                  | 50                   |
| 19.05                             | 0.75 | 203.2   | 8.0      | 101.6       | 4.0 | 1.0                                  | 10                   |
| 25.4                              | 1.0  | 203.2   | 8.0      | 101.6       | 4.0 | 1.0                                  | 10                   |
| 38.1                              | 1.5  | 304.8   | 12.0     | 152.4       | 6.0 | 0.1                                  | 1                    |
| 50.8                              | 2.0  | 304.8 to 406.4  | 12 to 16 | 203.2       | 8.0 | 0.1                                  | 1                    |

<sup>A</sup>A frequency of 100 MHz is permissible only with micrometer electrode system (Fig. 1).

specimen the same size as or smaller than the 50-mm (2 in.) diameter of the electrodes. Disk specimens are most suitable, but squares may be used if the length of the diagonal is slightly less than the diameter of the electrodes. Specimens 25 to 50 mm (1 to 2 in.) in diameter and up to 6.35 mm (0.25 in.) thick may be tested, and are placed loosely between and concentric with the electrodes, the preset fixed spacing of which must be slightly greater than the specimen thickness. It is recommended that the plate spacing be not much more than 10 % larger than the specimen thickness.

6.3.2 A prefabricated parallel-plate electrode system in which the plates are maintained parallel to each other at a predetermined spacing by means of suitable spacers of transparent fused quartz or polystyrene may be used to provide for testing larger and thicker specimens than can be used in the micrometer electrode system described in 6.3.1. The plates may have any suitable size up to 300 mm (12 in.) or more in diameter, or they may be square and up to at least 300 mm on a side.

6.4 Since the maximum measuring frequency permissible is dictated largely by the specimen size, specimen thickness, and electrode dimensions, Table 1 lists maximum frequency limits for different specimen sizes and thicknesses for convenience in choosing the most suitable arrangement. This information in general may be considered to apply to measurements made by either the direct contact electrode system or by the noncontacting (“air gap”) electrode system.

## 7. Test Specimens

7.1 *Test Specimen Selection*—Test the expanded cellular polymer material in the form of a sheet or a slab of any suitable thickness up to 50 mm. Select disk or square test specimens with opposing faces as nearly flat and plane parallel as possible. Select specimens from the larger sample in such a manner as to be representative of the material from which they are obtained.

NOTE 2—As originally prepared, slabs of expanded cellular polymers normally have a surface skin of density substantially greater than that of the major portion of the total volume. Unless otherwise specified or agreed upon, this surface skin shall be removed before performance of the relative permittivity and dissipation factor tests. In general, the choice in this matter may depend upon the way in which it is expected that the material will be used in service.

7.2 *Thickness*—Expanded cellular polymers are available in such a wide variety of types that the choice of the best method for measuring thickness in a particular case is left to the

judgment of the operator, or may be decided by agreement between or among the parties concerned. The principal precaution to be observed is that the specimen shall not be compressed or crushed during measurement of the thickness. Procedures similar to Method A (micrometer caliper) and Method C (dial-type gage) of Test Methods D 374 may be suitable for many types of materials. For flexible materials, or for rigid materials that may be very fragile, use Method H of Test Methods D 374. In general, at least five measurements of the thickness shall be made on each specimen, at points evenly distributed over their faces, and the values averaged.

7.3 *Dimensions*—The diameter of a disk specimen, or the side of a square specimen, should be at least eight times the thickness of the specimen, but in no case less than four times the thickness. The preferred specimen type and size in a given case will be dictated by the thickness of the material and also by the electrode system and maximum measuring frequency to be used in the tests (see Table 1).

## 8. Conditioning

8.1 Unless otherwise specified, the test specimens shall be tested without special conditioning, except that they shall be allowed to remain under the standard laboratory conditions of  $23 \pm 1^\circ\text{C}$ , and  $50 \pm 2\%$  relative humidity for a period of at least 16 h immediately prior to test.

## 9. Procedure

9.1 The requisite determinations of capacitance and loss associated with the particular specimen and electrode arrangement chosen in accordance with one of the suggested systems described in Section 5 shall be carried out, following the principles outlined in Test Methods D 150, except that for the noncontacting (“air gap”) systems the procedure shall be as follows:

9.1.1 Determine the change of capacitance,  $\Delta C$ , required to re-resonate the initially resonant circuit (or to rebalance the initially balanced bridge circuit) of which the parallel-plate dielectric sample holder is a part, after the test specimen has been inserted loosely between the parallel plates.

9.1.2 Determine the dissipation factor,  $D_e$ , of the specimen-air gap combination. The general principles for these two determinations shall be in accord with the recommended procedures for such measurements as outlined in Test Methods D 150.

## 10. Calculation

10.1 Calculate the relative permittivity  $K'_x$ , and dissipation factor,  $D_x$ , of the specimen in accordance with the methods prescribed in Test Methods D 150.

## 11. Report

11.1 Report the following information:

11.1.1 Complete sample identification,

11.1.2 Type and thickness of specimen,

11.1.3 Conditioning, if any,

11.1.4 Ambient temperature and relative humidity,

11.1.5 Electrode system employed,

11.1.6 Applied voltage, effective voltage gradient, and frequency, and

11.1.7 Relative permittivity, dissipation factor, and loss index for each specimen at each frequency of measurement.

## 12. Precision and Bias

12.1 Because of the nature of the materials and the wide range of thicknesses, densities, etc., covered by the general class of expanded cellular polymers, the overall precision and bias of the test results by these test methods will tend to be considerably poorer than those expected from measurements on solid-type insulating materials.

12.2 The precision (repeatability) of relative permittivity measurements by these test methods in general is considered to be such that when two tests are performed consecutively on the same specimen under identical conditions, the difference between the two results may normally be expected not to exceed  $\pm 3\%$  of their mean; or when the same specimen is tested first in one laboratory and then in another under the same conditions, the difference between the two test results (reproducibility) will normally not be expected to exceed about  $\pm 5\%$  of the mean for the two laboratories.

12.3 For dissipation factor measurements, the precision (repeatability) of these test methods is such that when two consecutive measurements are performed on the same specimen under identical conditions of frequency, temperature, electrode dimensions, etc., the difference between the two results will not normally be expected to exceed  $\pm 0.0002$  or  $\pm 5\%$  of their mean, whichever is larger. In interlaboratory tests on the same specimens under similar conditions, the difference between either result and the mean for the two laboratories (reproducibility) will not normally be expected to exceed  $\pm 0.0003$  or  $\pm 10\%$  of the mean, whichever is larger.

## 13. Keywords

13.1 capacitance; dielectric loss; dissipation factor; electrical insulation; expanded cellular material; loss index; permittivity (dielectric constant)

## APPENDIX

### (Nonmandatory Information)

#### X1. XI. RELATIONSHIP OF RELATIVE PERMITTIVITY OF EXPANDED CELLULAR MATERIAL TO DENSITY AND TO RELATIVE PERMITTIVITY OF BASE RESIN

X1.1 When the density of the expanded cellular polymer and the density and relative permittivity of the base resin are known, and assuming that the density of the gaseous component is negligible and its relative permittivity essentially unity, it is possible to calculate the relative permittivity of the expanded material to a fair degree of accuracy by use of either Eq X1.1 or Eq X1.2. This provides relative permittivity data for comparison with measured values.

$$K'_x = K'_p V_p \quad (\text{X1.1})$$

$$K'_x = \sqrt{K'_p/2 + N^2 + N} \quad (\text{X1.2})$$

where:

$K'_p$  = relative permittivity of the base resin solid component,

$V_p$  = volume fraction of the solid constituent, and

$N$  =  $\frac{1}{4} [1 - (K'_p - 1)(1 - 3V_p)]$ .

NOTE X1.1—Eq X1.1 is a special case of the well-known Lichtenecker logarithmic mixture formula for computing the dielectric constant,  $K'_x$ , of a two-component mixture, as follows:

$$\log K'_x = V_p \log K'_p + V_a \log K'_a \quad (\text{X1.3})$$

where  $V_p$  and  $V_a$  are the volume fractions, and  $K'_p$  and  $K'_a$  are the relative

permittivity, of the base material and added material, respectively, composing the mixture. Obviously  $V_p + V_a = 1$ . Eq X1.2 follows from the two-component mixture formula:<sup>5</sup>

$$(K'_x - K'_p)/3K'_s = V_a (K'_a - K'_p)/(K'_a + 2K'_x) \quad (\text{X1.4})$$

where:

$K'_x$  = relative permittivity of the mixture,

$K'_p$  = relative permittivity of the base material,


$K'_a$  = relative permittivity of the added material, and

$V_a$  =  $(1 - V_p)$  = volume fraction of the added material.

X1.2 The Boettcher Formula has been applied to the calculation of the relative permittivities of foamed polyethylene.<sup>6</sup> Its use gives slightly higher values of  $K'_x$  for expanded cellular polyethylene and polystyrene than are obtained by the logarithmic mixture formula which, however, is considerably simpler to use.

<sup>5</sup> Boettcher, C. J. F., *Receuil des Travaux Chimiques des Pays Bas*, Vol 64, 1945, p. 47.

<sup>6</sup> Windeler, A. S. *Bell System Technical Journal*, Vol XXXII, No. 5, Sept., 1953, pp. 1245–1256.

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