Designation: D 5470 – 95

An American National Standard

Standard Test Methods for Thermal Transmission Properties of Thin Thermally Conductive Solid Electrical Insulation Materials[1]

This standard is issued under the fixed designation D 5470; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This standard covers test methods for measuring thermal impedance of thin electrical insulation materials.

1.2 These test methods are useful with either homogeneous or composite thermally conductive sheet material ranging from 0.02 to 10 mm thickness.

1.3 The test methods measure steady-state heat flux through a flat specimen. Calculations are made as if the specimens were homogeneous. In fact, these materials are usually not homogeneous, but the assumption does not detract from the usefulness of the test methods.

1.4 The term "thermal conductivity" applies only to homogeneous materials. Thermally conductive electrical insulating materials are usually heterogeneous since they typically include fillers, binders, reinforcements such as glass fiber mesh, or a layer of polymeric film. To avoid confusion, this standard uses "apparent thermal conductivity" for measurements of both homogeneous and non-homogeneous materials.

1.5 A limitation of using these test methods to calculate apparent thermal conductivity is the problem of accurately determining the specimen thickness. To reflect the commercial practice of measuring thickness as manufactured rather than measuring thickness in an assembly, thickness is determined from measurements made at room temperature in accordance with Method C of Test Methods D 374.

1.6 Thermal impedance test data are influenced by contact pressures, specimen surface characteristics, and the existence of alternate paths for heat transmission which are not through the specimen. These test methods determine thermal conduction properties under a specific set of conditions (including a 50°C average test temperature) which may not agree exactly with the conditions in an application. As a result, the degree of correlation between these methods and any particular application needs to be determined.

1.7 The values stated in SI units are to be regarded as standard.

1.8 *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 374 Test Methods for Thickness of Solid Electrical Insulation[2]

E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method[3]

E 1225 Test Method for Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique[3]

2.2 *Military Specification:*

MIL-I-49456A Insulation Sheet, Electrical, Silicone Rubber, Thermally Conductive, Fiberglass Reinforced[4]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *average temperature (of a surface), n*— the area-weighted mean temperature.

3.1.2 *composite, n*—a material made up of distinct parts which contribute, either proportionally or synergistically, to the properties of the combination.

3.1.3 *heater/sensor, n*—an assembly consisting of electrically insulated wire-wound coils, one for applying a measured quantity of heat energy into the assembly and the second used to sense the temperature in the assembly.

3.1.4 *homogeneous material, n*—a material in which relevant properties are not a function of the position within the material.

3.1.5 *thermal conductivity* (λ), *n*—the time rate of heat flow, under steady conditions, through unit area, per unit temperature gradient in the direction perpendicular to the area.

3.1.6 *thermal impedance* (θ), *n*—the total opposition that an assembly (material, material interfaces) presents to the flow of heat.

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[1] 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 D09.19 on Dielectric Sheet and Roll Products.

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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 Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

3.1.7 *thermal interfacial impedance (contact resistance), n*—the temperature difference required to product a unit of heat flux at the contact planes between the specimen surfaces and the hot and cold surfaces in contact with the specimen under test. The symbol for contact resistance is R_I.

3.1.8 *thermal resistivity, n*—the reciprocal of thermal conductivity. Under steady-state conditions, the temperature gradient, in the direction perpendicular to the isothermal surface per unit of heat flux.

3.2 *Symbols:Symbols Used in This Standard:*

3.2.1 λ = thermal conductivity, watt per metre-K.

3.2.2 T_A = temperature of hot surface in contact with a specimen, K.

3.2.3 T_B = temperature of hot surface of a specimen, K.

3.2.4 T_C = temperature of cold surface of a specimen, K.

3.2.5 T_D = temperature of cold surface in contact with a specimen, K.

3.2.6 A = area of a specimen, m^2.

3.2.7 X = thickness of specimen, m.

3.2.8 Q = time rate of heat flow, W or J/s.

3.2.9 q = heat flux, or time rate of heat flow per unit area, W/m^2.

3.2.10 α = temperature coefficient of electrical resistance for the heater/sensor wire.

3.2.11 I = electrical current, A.

3.2.12 θ = thermal impedance, temperature difference per unit of heat flux, $(K \cdot m^2)/W$.

4. Summary of Test Methods

4.1 In Test Method A (a modification of Test Method E 1225) a specimen is sandwiched between two metal masses, compressed and supplied with a measured amount of heat energy. At equilibrium, temperatures are measured and a thermal impedance is calculated. The thermal impedance and thickness are used to compute apparent thermal conductivity.

4.2 Test Method B (Roiseland Heater/Sensor Method) utilizes a pair of heater/sensor elements having large area relative to a small specimen thickness, which reduces edge effects to a negligible value. A Wheatstone Bridge is used to obtain temperature differentials. The current is passed through both heaters, causing a temperature rise in both sensors. The sensors form two legs of a Wheatstone Bridge, and the bridge output corresponds to the temperature difference. Specimens (more than one layer) are placed between heat sinks of relatively large thermal mass and strong enough to resist deformation when placed in a press frame and subjected to the specified pressures. Thermal impedances are determined and apparent thermal conductivity is calculated.

5. Significance and Use

5.1 These test methods measure the thermal transmission properties of low modulus (deformable) dielectric materials. These materials are used to aid heat transfer in electrical and electronic applications.

NOTE 1—These test methods are useful with high modulus materials if layers of low modulus materials are combined with test specimens to exclude air from test interfaces.

5.2 These test methods are especially useful for generating thermal data on specimens that are too thin to be fitted with thermocouples for temperature sensing. The use of these test methods avoids problems of measurement due to non-uniform pressures, surface conditions, or techniques used to assemble electronic equipment.

5.3 In effect, the test methods assume that specimen layers coalesce and that there is no effective interfacial resistance between layers. The slope of the plot of thermal impedance against cumulative thickness permits the determination of thermal conductivity without regard to thermal interfacial impedance.

5.4 These test methods are approved for use by the Department of Defense, and are included in Military Specification MIL-I-49456A.

TEST METHOD A—GUARDED HEATER METHOD

6. Apparatus

6.1 General features are shown in Fig. 1 and Fig. 2. The

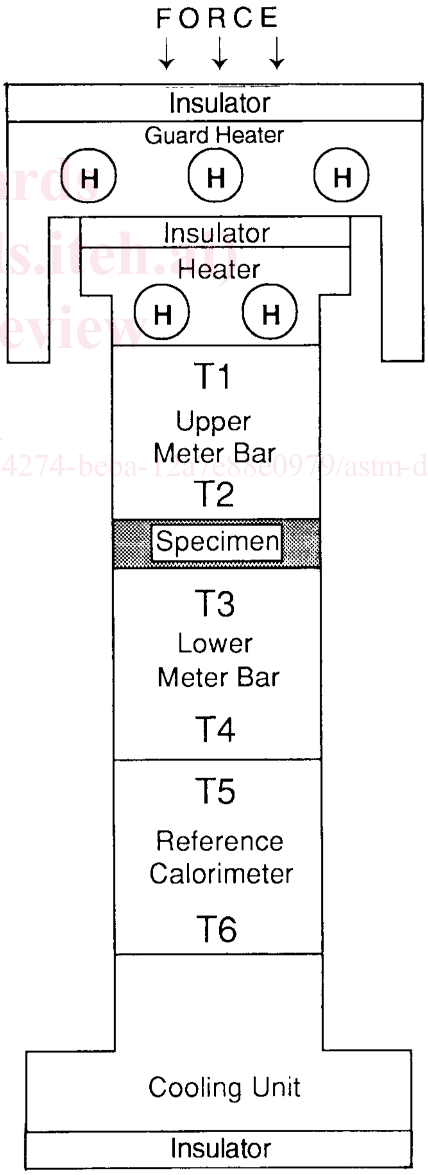

FIG. 1 Guarded Heater with Reference Calorimeter

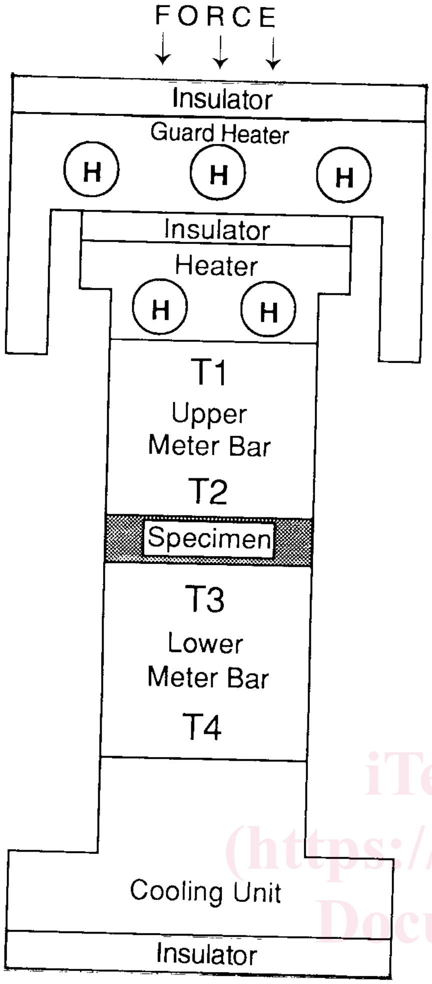

FIG. 2 Guarded Heater

apparatus shown in Fig. 1 uses a reference calorimeter to determine rate of heat flow through the specimen. Optionally omit the reference calorimeter (Fig. 2). The rate of heat flow in the specimen is determined from the electrical power applied to the heater. Smoothly finish all contacting surfaces to within 0.4 µm to approximate a true plane for the metre bars in contact with the specimen surface.

6.2 The heater unit (or block) is made of copper or other highly conductive material, containing cartridge or similar wire wound heaters. It is separated from a surrounding guard heater by a layer of thermal insulation material (epoxy FR-4 or similar) 5 mm thick. The guard heater is also insulated from the press and ensures that all measured energy is transformed to the upper metre bar.

6.3 Metre bars are constructed from high thermal conductivity material having parallel working surfaces. A suitable material of construction is a high purity grade aluminum.

6.4 The reference calorimeter is constructed from a material which has a known thermal conductivity over the range of test temperatures to be used. A recommended material is SRM-1462 austenitic stainless steel. Test Method E 1225 lists other useful materials of construction.

6.5 The cooling unit is a metal block cooled by fluid supplied from a constant temperature bath such that the temperature is maintained uniformly within ±0.2 K.

6.6 The press is capable of transmitting the specified force to the test fixture through a free-floating spherical seat attachment, to prevent offset loads and uneven pressures on the test specimen.

6.7 Insulation surrounding the specimen stack, if used, is a fibrous thermal insulating blanket (see 8.8).

7. Test Specimens for Test Method A

7.1 For thermal impedance: Make the specimen from a piece of the test material, the same area (length and width) as the metering bars. Unless previously known, and prior to placement into the assembly, measure the thickness of the piece in accordance with Method C of Test Methods D 374.

7.2 For apparent thermal conductivity: prepare a sufficient number of specimens to provide the required number of layers (see 8.11).

7.3 Specimen conditioning: Unless otherwise specified, test the specimens in the as-received state. Remove any dirt or other obvious secondary contamination by a suitable non-reaction solvent prior to testing. To ensure the removal of cleaning solvents, use suitable drying procedures after any cleaning.

8. Procedure for Test Method A

8.1 At room temperature, measure the specimen thickness in accordance with Method C of Test Methods D 374.

8.2 Center the specimen between the two metre bars.

8.3 Insert the reference calorimeter, if used, between the lower metre bar and the cooling unit.

8.4 Place the assembled test stack into the press.

8.5 With the press, apply a force to the stack such that 3.0 ± 0.1 MPa pressure is applied to the specimen. Maintain this pressure on the stack for the duration of the test.

NOTE 2—A pressure of 3.0 MPa is adequate to reduce to a negligible level the effects of contact resistance between the specimen and the water bars due to minor surface irregularities.

8.6 Circulate cooling fluid and apply power to the heating element. Maintain the guard heater temperature to within ±0.2 K of the heater temperature.

8.7 Since the pressure may increase during heatup, monitor and adjust the applied force in the press to counteract the increased pressure on the specimen due to thermal expansion.

8.8 Conduct the testing under conditions that produce an average specimen temperature of 50°C. For measurements made at temperatures above 300 K, it is necessary to apply a fibrous thermal insulating blanket loosely around the calorimeter sections.

8.9 Record the temperatures of the metre bars and the reference calorimeter at equilibrium. In the absence of a reference calorimeter, record the voltage and current applied to the heater. Equilibrium is attained when 2 successive sets of temperature readings are taken at 15 min intervals and the differences between the two are less than ±0.2 K.

8.10 Calculate the mean specimen temperature and the thermal impedance. Label the calculated thermal impedance for the single-layer specimen as the "thermal impedance" of the specimen.

8.11 Determine the thermal impedance of multiple layers.