ASTM INTERNATIONAL

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Standard Test Method for
Thermal Transmission Properties of Thermally Conductive Electrical Insulation Materials[1]

This standard is issued under the fixed designation D5470; 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 U.S. Department of Defense.

1. Scope*

1.1 This standard covers a test method for measurement of thermal impedance and calculation of an apparent thermal conductivity for thermally conductive electrical insulation materials ranging from liquid compounds to hard solid materials.

1.2 The term "thermal conductivity" applies only to homogeneous materials. Thermally conductive electrical insulating materials are usually heterogeneous and to avoid confusion this test method uses "apparent thermal conductivity" for determining thermal transmission properties of both homogeneous and heterogeneous materials.

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

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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D374 Test Methods for Thickness of Solid Electrical Insulation (Metric) D0374_D0374M

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

E1225 Test Method for Thermal Conductivity of Solids Using the Guarded-Comparative-Longitudinal Heat Flow Technique

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

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

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

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

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

3.1.6 *thermal interfacial resistance (contact resistance), n*—the temperature difference required to produce 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.

A Summary of Changes section appears at the end of this standard

1

3.1.7 *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 Used in This Standard:*

3.2.1 λ = apparent thermal conductivity, W/m·K.

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

3.2.3 d = thickness of specimen, m.

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

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

3.2.6 θ = thermal impedance, temperature difference per unit of heat flux, (K·m^2)/W.

4. Summary of Test Method

4.1 This standard is based on idealized heat conduction between two parallel, isothermal surfaces separated by a test specimen of uniform thickness. The thermal gradient imposed on the specimen by the temperature difference between the two contacting surfaces causes the heat flow through the specimen. This heat flow is perpendicular to the test surfaces and is uniform across the surfaces with no lateral heat spreading.

4.2 The measurements required by this standard when using two meter bars are:

T_1 = hotter temperature of the hot meter bar, K,

T_2 = colder temperature of the hot meter bar, K,

T_3 = hotter temperature of the cold meter bar, K,

T_4 = colder temperature of the cold meter bar, K,

A = area of the test surfaces, m^2, and

d = specimen thickness, m.

4.3 Based on the idealized test configuration, measurements are taken to compute the following parameters:

T_H = the temperature of the hotter isothermal surface, K,

T_C = the temperature of the colder isothermal surface, K,

Q = the heat flow rate between the two isothermal surfaces, W,

thermal impedance = the temperature difference between the two isothermal surfaces divided by the heat flux through them, K·m^2/W, and

apparent thermal conductivity = calculated from a plot of specimen thermal impedance versus thickness, W/m·K.

4.4 Interfacial thermal resistance exists between the specimen and the test surfaces. These contact resistances are included in the specimen thermal impedance computation. Contact resistance varies widely depending on the nature of the specimen surface and the mechanical pressure applied to the specimen by the test surfaces. The Measure and record the clamping pressure applied to the specimen should therefore be measured and recorded as a secondary measurement required for the method except in the case of fluidic samples (Type I, see section 5.3.1) where the applied pressure is insignificant. The computation for thermal impedance is comprised of the sum of the specimen thermal resistance plus the interfacial thermal resistance.

4.5 Calculation of apparent thermal conductivity requires an accurate determination of the specimen thickness under test. Different means can are able to be used to control, monitor, and measure the test specimen thickness depending on the material type.

4.5.1 The test specimen thickness under test can is able to be controlled with shims or mechanical stops if the dimension of the specimen can change during the test.

4.5.2 The test specimen thickness can is able to be monitored under test with an in situ thickness measurement if the dimension of the specimen can change during the test.

4.5.3 The test specimen thickness can is able to be measured as manufactured at room temperature in accordance with Test Methods D374 Test Method C if it exhibits negligible compression deflection.

5. Significance and Use

5.1 This standard measures the steady state thermal impedance of electrical insulating materials used to enhance heat transfer in electrical and electronic applications. This standard is especially useful for measuring thermal transmission properties of specimens that are either too thin or have insufficient mechanical stability to allow placement of temperature sensors in the specimen as in Test Method E1225.

5.2 This standard imposes an idealized heat flow pattern and specifies an average specimen test temperature. The thermal impedances thus measured cannot be directly applied to most practical applications where these required uniform, parallel heat conduction conditions do not exist.

5.3 This standard is useful for measuring the thermal impedance of the following material types.

5.3.1 *Type I*—Viscous liquids that exhibit unlimited deformation when a stress is applied. These include liquid compounds such as greases, pastes, and phase change materials. These materials exhibit no evidence of elastic behavior or the tendency to return to initial shape after deflection stresses are removed.

5.3.2 *Type II*—Viscoelastic solids where stresses of deformation are ultimately balanced by internal material stresses thus limiting further deformation. Examples include gels, soft, and hard rubbers. These materials exhibit linear elastic properties with significant deflection relative to material thickness.

5.3.3 *Type III*—Elastic solids which exhibit negligible deflection. Examples include ceramics, metals, and some types of plastics.

5.4 The apparent thermal conductivity of a specimen ~~can~~ is able to be calculated from the measured thermal impedance and measured specimen thickness if the interfacial thermal resistance is insignificantly small (nominally less than 1 %) compared to the thermal resistance of the specimen.

5.4.1 The apparent thermal conductivity of a sample material ~~can~~ is able to be accurately determined by excluding the interfacial thermal resistance. This is accomplished by measuring the thermal impedance of different thicknesses of the material under test and plotting thermal impedance versus thickness. The inverse of the slope of the resulting straight line is the apparent thermal conductivity. The intercept at zero thickness is the sum of the contact resistances at the two surfaces.

5.4.2 The contact resistance ~~can~~ is able to be reduced by applying thermal grease or oil to the test surfaces of rigid test specimens (Type III).

TEST METHOD

6. Apparatus

6.1 The general features of an apparatus that meets the requirements of this method are shown in Figs. 1 and 2. This apparatus
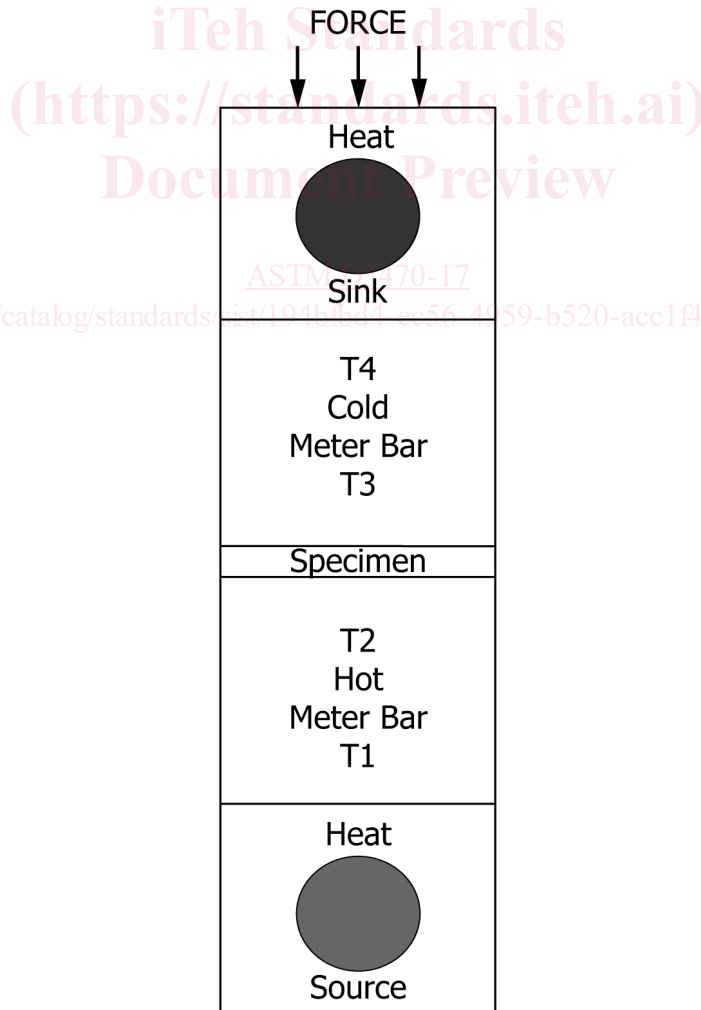
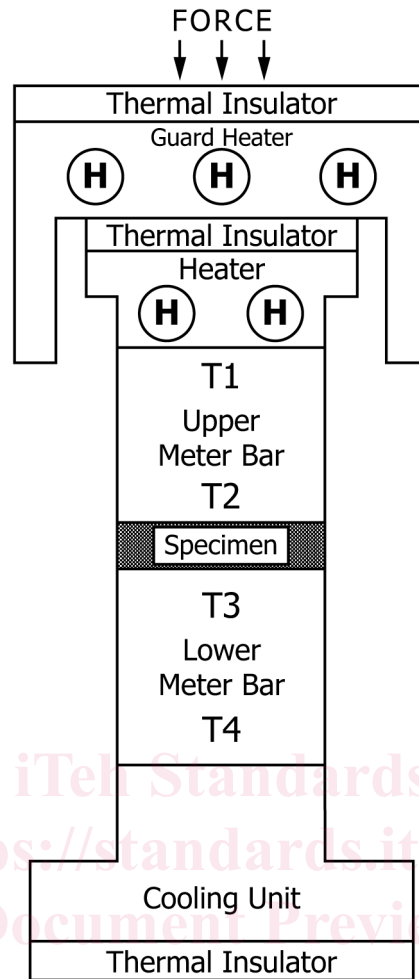FIG. 1 Test Stack Using ~~the~~ Meter Bars as Calorimeters

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FIG. 2 Guarded Heater Test Stack

imposes the required test conditions and accomplishes the required measurements. It ~~should be considered to be~~ is one possible engineering solution, not a uniquely exclusive implementation.

6.2 The test surfaces are to be smooth within 0.4 microns and parallel to within 5 microns.

6.3 The heat sources are either electrical heaters or temperature controlled fluid circulators. Typical electrical heaters are made by embedding wire wound cartridge heaters in a highly conductive metal block. Circulated fluid heaters consist of a metal block heat exchanger through which a controlled temperature fluid is circulated to provide the required heat flow as well as temperature control.

6.4 Heat flow through the specimen ~~can~~ is able to be measured with meter bars regardless of the type of heater used.

6.4.1 Electrical heaters offer convenient measurement of the heating power generated but must be combined with a guard heater and high quality insulation to limit heat leakage away from the primary flow through the specimen.

6.4.2 Heat flow meter bars ~~can~~ are able to be constructed from high conductivity materials with well documented thermal conductivity within the temperature range of interest. The temperature sensitivity of thermal conductivity must be considered for accurate heat flow measurement. The thermal conductivity of the bar material is recommended to be greater than 50 W/m·K.

6.4.3 Guard heaters are comprised of heated shields around the primary heat source to eliminate heat leakage to the environment. Guard heaters are insulated from the heat source and maintained at a temperature within ±0.2 K of the heater. This effectively reduces the heat leakage from the primary heater by nullifying the temperature difference across the insulation. Insulation between the guard heater and the heat source ~~should~~ will be at least the equivalent of one 5 mm layer of FR-4 epoxy material.

6.4.4 If the heat flow meter bars are used on both the hot and cold surfaces, guard heaters and thermal insulation is not required and the heat flow through the test specimen is computed as the average heat flow through both meter bars.

6.5 Meter bars ~~can~~ are able to also be used to determine the temperature of the test surfaces by extrapolating the linear array of meter bar temperatures to the test surfaces. This ~~can~~ is able to be done for both the hot side and cold side meter bars. Surface