Designation: D 5470 – 95 An American National Standard

薄型热导刚性电绝缘材料的热传导特性的测试方法.

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. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by 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 [redacted] in accordance with [redacted]

1.6 Thermal impedance test data are influenced by [redacted] 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 *Descriptions 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.

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

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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.

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 = 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·m^2)/W.

4. Summary of Test Methods

4.1 In Test Method A ([redacted]ation of Test Method [redacted]) 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 Figs. 1a and 1b. The apparatus shown in Fig. 1a uses a reference calorimeter to determine rate of heat flow through the specimen. [redacted]mit the reference calorimeter (Fig. 1b). 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.

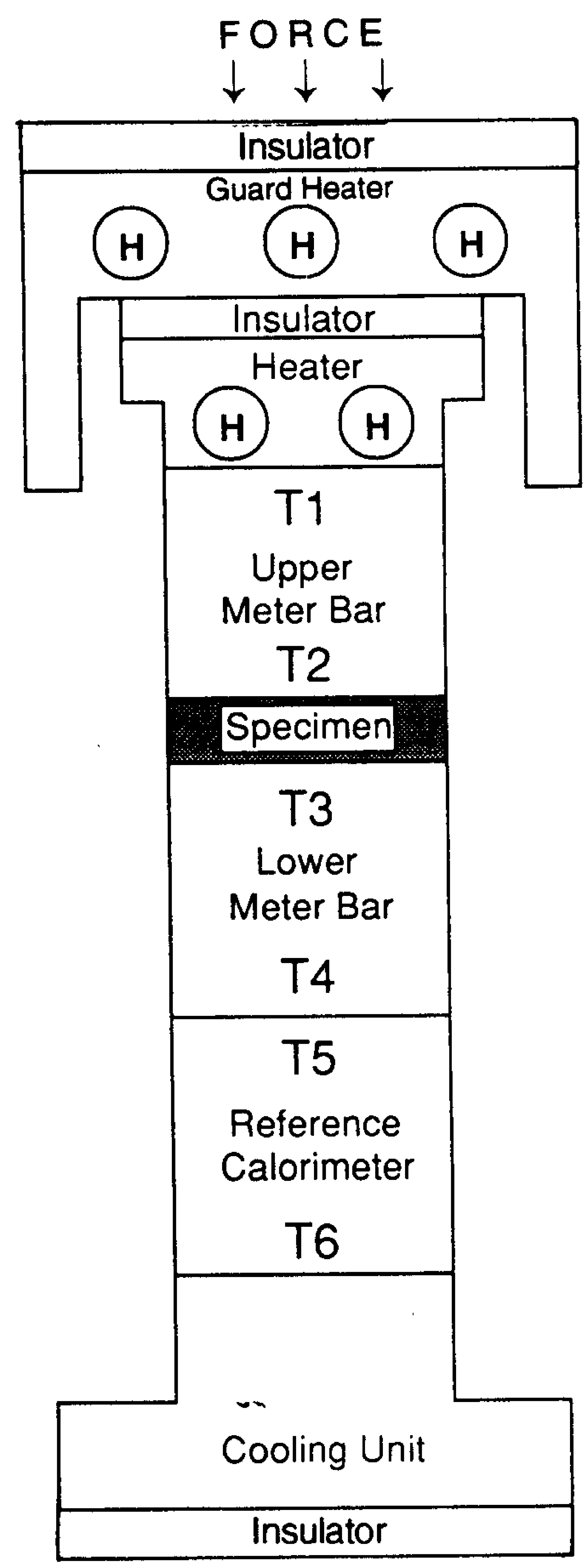

FIG. 1a Guarded Heater with Reference Calorimeter

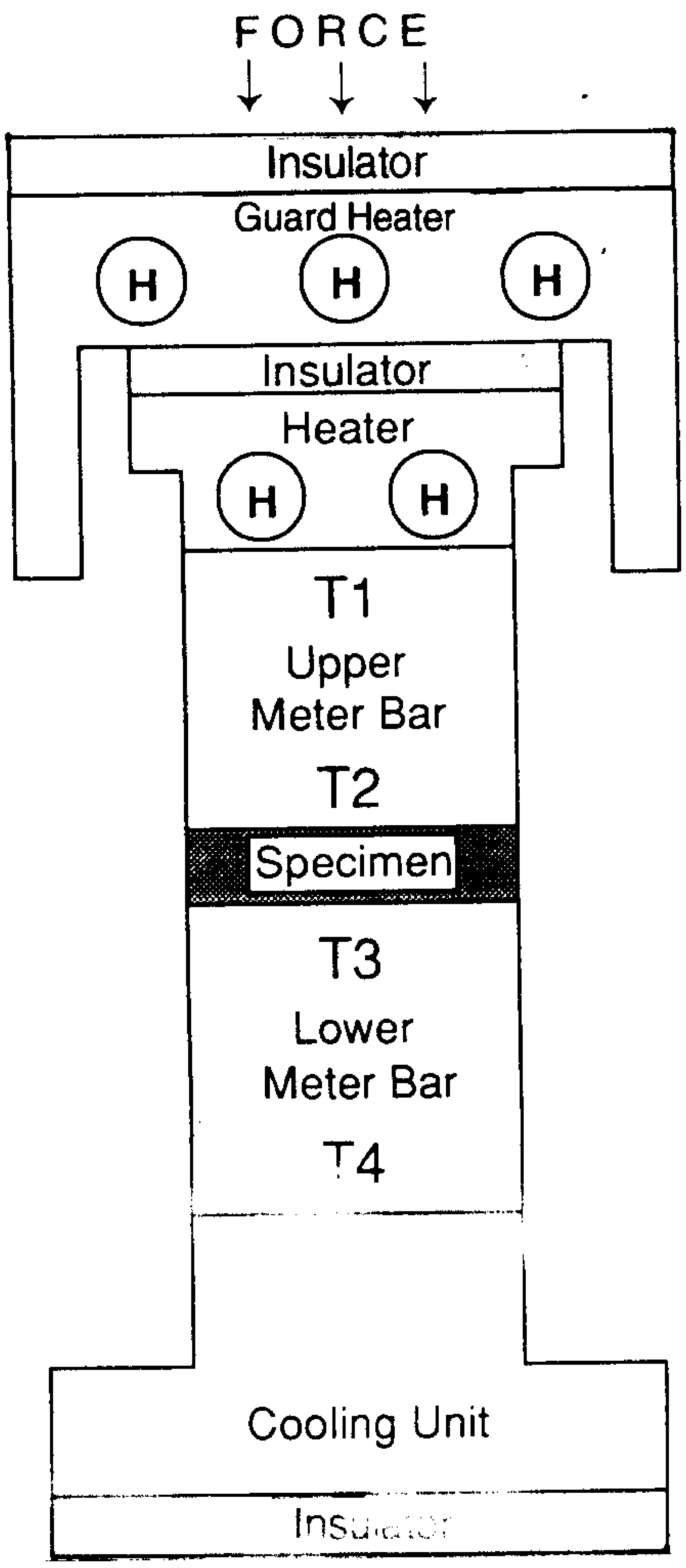

FIG. 1b Guarded Heater

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. Maintain the mean temperature of the multiple-layered specimens within ±2 K of the single layer specimen temperature by reducing the heat flux as the number of layers is increased.

9. Calculation for Test Method A

9.1 *Thermal Impedance:*

9.1.1 Heat flow using reference calorimeter. Calculate the heat flow from the reference calorimeter readings as follows:

$$Q = \frac{\lambda_R \times A}{d} \times [T_5 - T_6] \quad (1)$$

where:

Q = heat flow, W,
λ_R = thermal conductivity of the reference calorimeter material, W/(m·K),
A = area of the reference calorimeter, m^2,
$T_5 - T_6$ = temperature difference between thermocouples of the reference calorimeter, K, and
d = distance between thermocouples in the reference calorimeter, m.

9.1.2 Heat flow when not using reference calorimeter. Calculate the heat flow from the applied electrical power as follows:

$$Q = V \times I \quad (2)$$

where:

Q = heat flow, W,
V = electrical potential applied to the heater, V, and
I = electrical current flow in the heater, A.

9.2 Derive the temperature of the upper metre bar surface in contact with the specimen from the following:

$$T_A = T_2 - \frac{d_B}{d_A}(T_1 - T_2) \quad (3)$$

where:

T_A = temperature of the upper metre bar surface in contact with the specimen, K,
T_1 = upper temperature of the upper metre bar, K,
T_2 = lower temperature of the upper metre bar, K,
d_A = distance between temperature sensors, m, and
d_B = distance from the lower sensor to the lower surface of the upper metre bar, m.

9.3 Derive the temperature of the lower metre bar surface in contact with the specimen from the following:

$$T_D = T_3 + \frac{d_D}{d_C}(T_3 - T_4) \quad (4)$$

where:

T_D = temperature of the lower metre bar surface in contact with the specimen, K,
T_3 = upper temperature of the lower metre bar, K,
T_4 = lower temperature of the lower metre bar, K,
d_C = distance between temperature sensors, m, and
d_D = distance from the upper sensor to the upper surface of the lower metre bar, m.

9.4 Calculate the thermal impedance from

$$\theta = (T_A - T_D) \times A/Q \quad (5)$$

and express it in units of (K·m^2)/W.

9.5 Obtain apparent thermal conductivity from a plot of thermal impedance for single and multiple layered specimens against the respective specimen thickness. Plot values of the specimen thickness on the x axis and specimen thermal impedance on the y axis.

9.5.1 The curve is a straight line whose slope is the reciprocal of the apparent thermal conductivity. The intercept at zero thickness is the thermal interfacial impedance, R_I specific to the sample, clamping force used, and the clamping surfaces.

9.5.2 As a preferred alternative, compute the slope and the intercept using least mean squares.

TEST METHOD B—ROISELAND HEATER/SENSOR METHOD

10. Apparatus

10.1 *General*—Schematic diagrams of the assembly, instrumentation, and heater/sensor element are shown in Figs. 2, 3, and 4, respectively.

10.2 *Conditions*—The test temperature of 50°C is established by placing the assembly in a temperature control chamber, or alternatively by pumping controlled temperature water through channels in the aluminum heat sinks.

10.3 *Press*—Clamping force is supplied by a spring, screw, or hydraulic press to maintain essentially constant force with changes in operating temperature. The pressure applied to the specimen is determined by the force applied and the contact area of the heater/sensor assembly.

10.4 *Heater/Sensor*—The heater/sensor assembly has parallel strands of No. 40 AWG single strand copper wire having essentially identical resistances at 293 K. The surface areas of the two heater/sensors are closely matched. Details are shown in Fig. 4.

10.5 *Thermal Shim*—Thin (25 μm) polyester or polyeth-

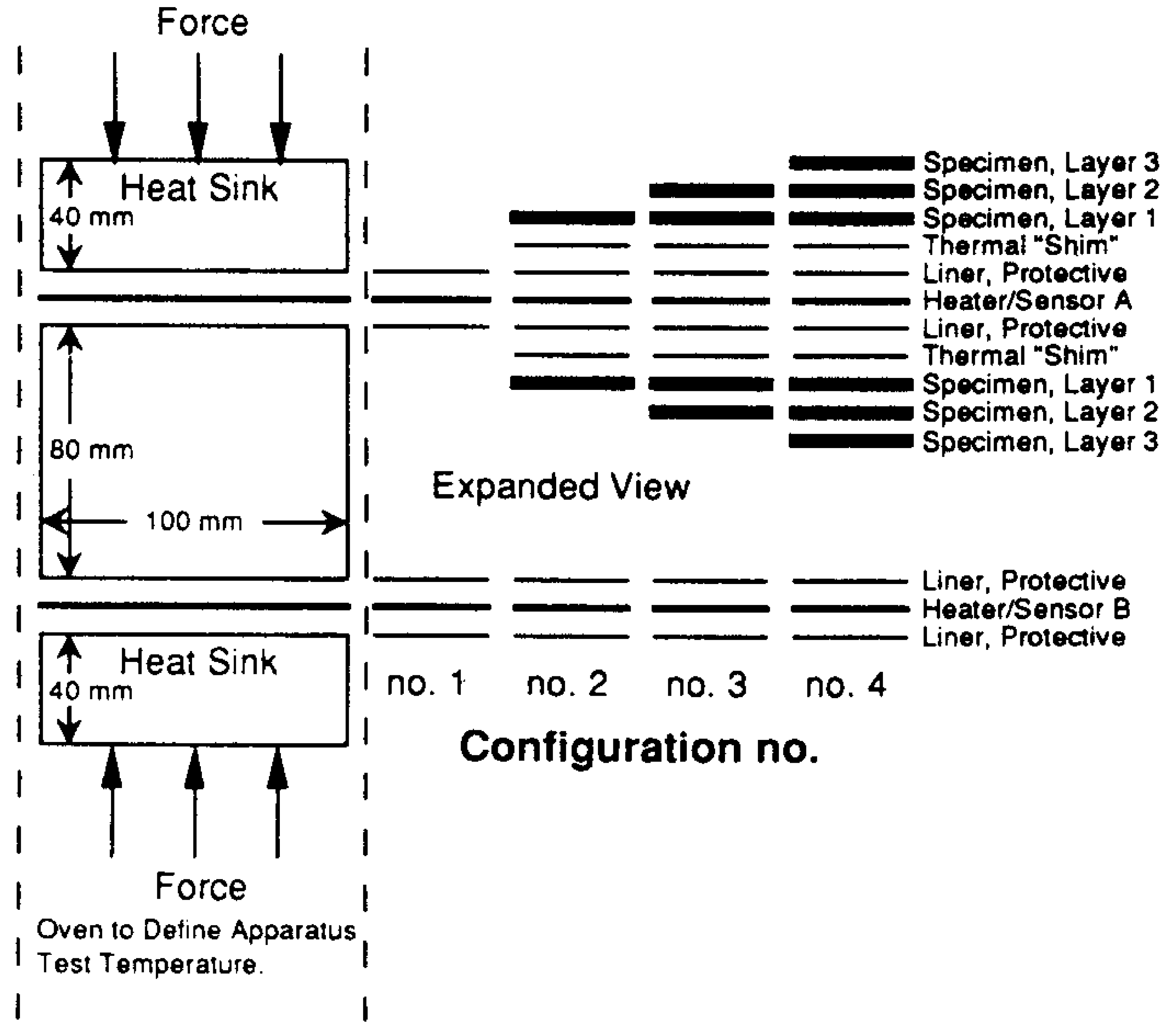

FIG. 2 Test Fixture for Test Method B

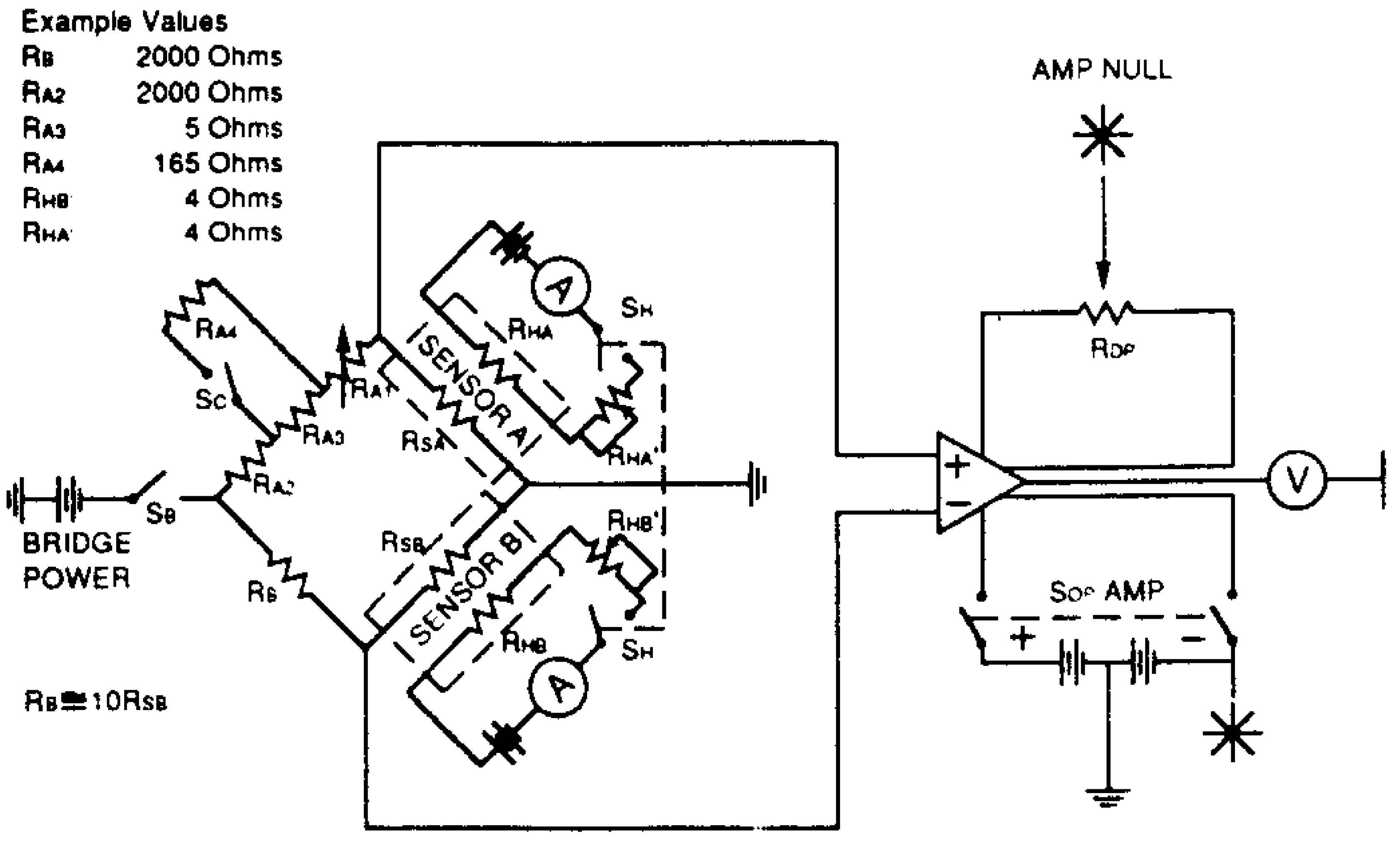

FIG. 3 Instrumentation for Test Method B

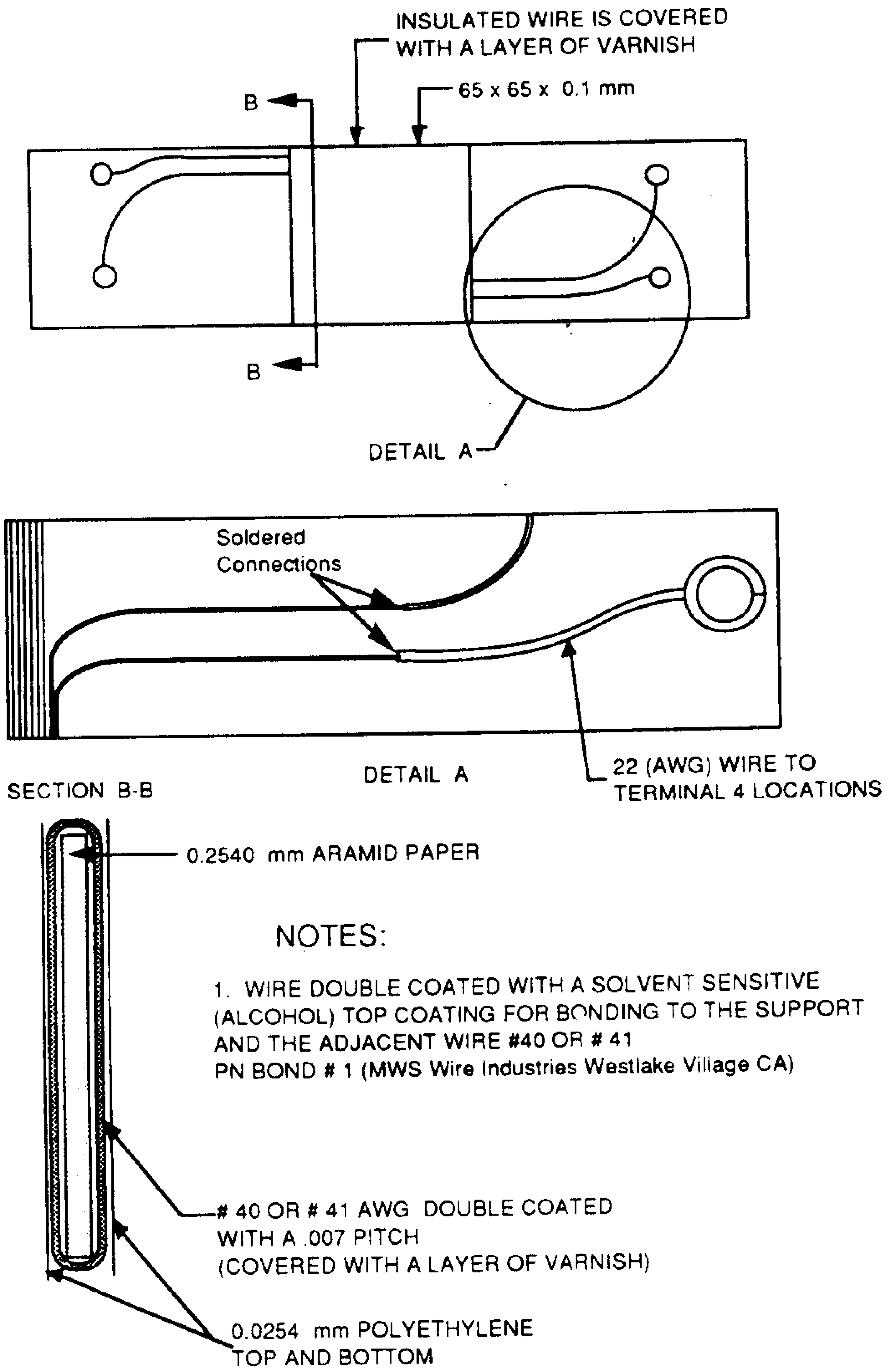

FIG. 4 Heater/Sensor for Test Method B

ylene film used to thermally bias the assembly to give a small, positive value for initial bridge amplifier output. Thermal shims are used in pairs, above and below the heater/sensor.

10.6 *Protective Liner*—A thin, resilient and flexible film material is used to protect the heater/sensors from sample adhesion and to minimize the strain sensitivity of the heater/sensors.

10.7 *Wheatstone Bridge*—The Wheatstone Bridge compensates for the zero shift that would be associated with small temperature changes of the heater/sensor assembly, and permits the apparatus to be operated over a wide range of temperatures.

10.8 *Amplifier*—The assembly uses an amplifier with a gain of 2000.

NOTE 3—High gain amplifiers require careful attention to shielding of the apparatus wire harness. This is a function of the instrumentation, and is not a characteristic of the test.

10.9 *Metreing*—Metres are required for measuring heater/sensor resistance (100 to 500 Ω within ±0.5 %), heater current (0 to 2 A within ±1 %), and amplifier output (0 to 2 dc V within ±0.2 %).

11. Test Specimens for Test Method B

11.1 Six pieces normally comprise a specimen. Replicate measurements require additional specimens. Cut six pieces from the sample, each having a length and width greater than that of the heater/sensor. The dimensions of the heater/sensor define the effective measurement area.

11.2 Test all specimens in as received condition unless otherwise specified.

12. Apparatus Set-up for Test Method B

12.1 Measure the thickness of the specimen pieces using Method C of Test Methods D 374. Match the pieces for thickness, for use in 12.4.

12.2 Determine the bridge constant (C_B):

12.2.1 Determine R_{HA}, R_{HB} ± 2 Ω at 273°K.

12.2.2 Determine Sensor Resistance R_{SA}, R_{SB} ± 2 Ω at 273°K.

12.2.3 Determine Bridge Resistance Values R_{A3}, R_{A4}, R_B ± 1 Ω.

12.2.4 Use α (handbook value for copper).

12.2.5 Calculate:

$$C_B = \frac{2R_{SB}(R_{A3})^2}{\alpha R_{HA} R_{SA} R_B (R_{A3} + R_{A4})} \tag{6}$$

12.3 Determine A, the one side effective measurement area of the heater/sensor.

12.4 Maintain a specimen temperature of 50°C by placing the press assembly in a temperature controlled chamber or by pumping controlled temperature water through channels in the aluminum heat sinks.

12.5 Adjust the assembly.

12.5.1 Place heater/sensors, liners, and thermal shims in the apparatus as shown in configuration 1 of Fig. 2, and apply force to achieve a pressure of 3 MPa on the heater/sensor area.

12.5.2 Turn on bridge amplifier (S_{AMP}) and adjust output to near zero.

12.5.3 Turn on bridge power (S_{BRIDGE}) and adjust R_{A1} to give bridge amplifier output of near zero.

12.5.4 Turn on heater power (S_{HEATER}) for 10 to 15 s. Equalize the heater currents I_{HA} and I_{HB} using ballast resistors $Q_{HA'}$ and $Q_{HB'}$. If a small positive amplifier output voltage shift is sensed, proceed to 12.5.7.

12.5.5 If a small positive reading shift is not obtained, adjust the number of thermal shims, adding or removing shims in pairs, until a small positive shift is obtained. Proceed to 12.5.7.

12.5.6 Record amplifier output voltage with power on for 15 s (V_o on) and again after power has been turned off for 15 s (V_o off).

NOTE 4—Zeroing steps are not critical as long as the algebraic sign of the initial values is maintained.

12.5.7 Turn off heater power, bridge power and amplifier power.

13. Procedure for Test Method B

13.1 Rearrange the assembly to correspond to configuration 2 of Fig. 2 by adding a piece of the specimen above and below the heater/sensor in cavity A. Apply clamping force for 1 h (3 MPa).

13.2 Turn on bridge and bridge amplifier power (S_{AMP} and S_{BRIDGE}).

13.3 Turn on heaters (S_{HEATER}). Equalize currents I_{HA} and I_{HB} as in 12.5.4. After 15 s record bridge amplifier output (V_1 on).

13.4 Turn heaters off. After 15 s record bridge amplifier output (V_1 off).

13.5 Add pieces of specimen to each side of heater/sensor to conform to configuration 3 of Fig. 2. Leave under clamping force for 1 h.

13.6 Repeat 13.2 through 13.4, recording bridge amplifier output as V_2 on and V_2 off.

13.7 Add pieces of specimen to each side of heater/sensor to conform with configuration 4 of Fig. 2. Leave under clamping force for 1 h.

13.8 Turn on heaters (S_{HEATER}). Equalize currents I_{HA} and I_{HB} as in 12.5.4. After 15 s record bridge amplifier output (V_3 on) and heater current (I).

13.9 Turn off heater (S_{HEATER}). After 15 s record bridge amplifier output (V_3 off).

13.10 Turn on calibration switch (S_{CAL}). After 10 s record bridge amplifier output as V_{CAL}.

13.11 Turn off bridge power, bridge amplifier power and calibration switch.

NOTE 5—Adjustment of the current is required to minimize changes in the I^2 term. With each successive specimen layer, the heater temperature will change as will the electrical resistance of the heater. These changes are very small and not significant.

14. Calculation

14.1 Calculate:

$$V_0 \text{ where } V_0 = V_0 \text{ on} - V_0 \text{ off}$$
$$V_1 \text{ where } V_1 = V_1 \text{ on} - V_1 \text{ off}$$
$$V_2 \text{ where } V_2 = V_2 \text{ on} - V_2 \text{ off}$$
$$V_3 \text{ where } V_3 = V_3 \text{ on} - V_3 \text{ off}$$
$$V_C \text{ where } V_C = V_{CAL} - V_3 \text{ off}$$

14.2 For each configuration, calculate thermal impedance (θ) as follows:

14.2.1

$$\theta_{\text{LAYER 1}} = \frac{V_1 - V_0}{V_C \times I^2}(C_B \times A) \quad (7)$$

NOTE 6—$\theta_{\text{LAYER 1}}$ is Thermal Impedance referred to in MIL-I-49456A.

14.2.2

$$\theta_{\text{LAYERS 1 and 2}} = \frac{V_2 - V_0}{V_C \times I^2}(C_B \times A) \quad (8)$$

14.2.3

$$\theta_{\text{LAYERS 1, 2 and 3}} = \frac{V_3 - V_0}{V_C \times I^2}(C_B \times A) \quad (9)$$

14.2.4 When A is in metres, θ is expressed as $(K \cdot m^2)/W$.

14.3 *Thermal Conductivity Computation:*

14.3.1 Obtain the apparent thermal conductivity of the sample from a plot of thermal impedance for single and multiple layers. Plot the cumulative layer thickness on the X axis and the cumulative layer thermal impedance on the Y axis. The plot is a straight line whose slope is the reciprocal of apparent thermal conductivity.

14.3.2 As a preferred alternative, compute the slope and intercept using least mean squares. The zero intercept is the thermal interfacial impedance (R_I) specific to the sample, the clamping force used, and the clamping surfaces. The zero intercept is not a specific material property.

15. Report

15.1 Report the following information:

15.1.1 Test Method used (Method A or Method B).

15.1.2 Specimen identification:

15.1.2.1 Name of the manufacturer,

15.1.2.2 Batch or lot number,

15.1.2.3 Grade designation,

15.1.2.4 Nominal thickness, and

15.1.2.5 Any other information pertinent to the identification of the material.

15.1.3 Number of layers used in the test.

15.1.4 Average temperature of the specimen, if another than 323 K.

15.1.5 Pressure used during testing, if other than 3.0 MPa.

15.1.6 Thermal transmission properties:

15.1.6.1 Apparent thermal conductivity,

15.1.6.2 Thermal impedance from 9.4 or 14.2.1, and

15.1.6.3 Thermal interfacial impedance from 9.5.1 or 14.3.2.

16. Precision and Bias

16.1 A round robin was conducted on five materials having different constructions and thicknesses. Six laboratories tested specimens from all of the materials using either Test Method A or B of this standard. Table 1, prepared in accordance with Practice E 691, summarizes the results of the round robin. Data obtained during the round robin testing are being made available in a research report.

16.2 From the data used to generate Table 1 the following conclusion is made:

16.2.1 Thermal conductivity values for the same material measured in different laboratories are expected to be within 18 % of the mean of the values from all of the laboratories.

16.3 Bias for these test methods is currently under investigation subject to the availability of a suitable reference material.

17. Keywords

17.1 apparent thermal conductivity; guarded heater method; MIL-I-49456A; Roiseland method; thermal conductivity; thermal impedance; thin, thermally conductive insulation

TABLE 1 Precision for Conductivity Measurement

NOTE—Values are in units of: watt per metre Kelvin.

Material Identity	Average	S_r[A]	S_R[B]	r[C]	R[D]
Material B	0.923	0.0383	0.163	0.107	0.456
Material E	1.245	0.0834	0.175	0.234	0.491
Material C	1.311	0.0423	0.192	0.119	0.536
Material A	2.732	0.2010	0.311	0.563	0.872
Material D	5.445	0.5691	0.711	1.594	1.991

[A] S_r = the within-lab standard deviation of the average.
[B] S_R = the between-labs standard deviation of the average.
[C] r = the within-lab repeatability limit = 2.8 × S_r.
[D] R = the between-labs reproducibility limit = 2.8 × S_R.

APPENDIX

(Nonmandatory Information)

X1.1 PREPARATION OF HEATER/SENSOR FOR TEST METHOD B

X1.1 The heater/sensors used in developing Test Method B were prepared in the following manner:

X1.1.1 Wrap a 41.1 mm diameter steel mandrel with two layers of release paper to prepare a 41.3 mm form.

X1.1.2 Wind parallel strands of 40 or 41 gage insulated wire on the mandrel at a 0.007 in. pitch, using a lathe or coil winding machine.

X1.1.3 Coat the coil with a flexible adhesive. (With the use of MWS Wire Industries PN Bond, a dilute solution of Zytel 61® in ethanol is suitable.)

X1.1.4 Force the parallel wire coil assembly from the mandrel and remove the release paper.

X1.1.5 Insert a 64.5 mm strip of epoxy coated ARAMID[5] fiber paper into the coil, and flatten the coil over the paper.

X1.1.6 Apply a flexible epoxy varnish, or use additional coating prepared using the solution in X1.1.3. Arrange the lead wires as shown in Fig. 4.

X1.1.7 Press the assembly between two 1/4 in. (6 mm) glass plates using silicone coated film release liners. Cure or heat set the assembly, depending on the varnish used. Remove the liners.

X1.1.8 As a strain relief, solder 22 gage stranded wire from the leads to the terminals.

[5] Available from Active Industries, 7850 Quincy St., Willowbrook, IL 60521.