INTERNATIONAL

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# Standard Test Method for Evaluating the Resistance to Thermal Transmission by the Guarded Heat Flow Meter Technique[1]

This standard is issued under the fixed designation E1530; 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 describes a steady-state technique for the determination of the resistance to thermal transmission (thermal resistance) of materials having a thickness of less than 25 mm. Thermal conductivity may be determined for homogeneous opaque solid specimens (see Note 1). This test method is particularly useful for homogeneous, multilayer, and composite specimens having a thermal resistance in the range from 10 $(cm)^2·K·W^{-1}$ to 400 $(cm)^2·K·W^{-1}$, which may be obtained from materials with an approximate thermal conductivity range 0.1 $W·m^{-1}·K^{-1}$ to 30 $W·m^{-1}·K^{-1}$ over the approximate temperature range from 150 K to 600 K. It can be used outside these ranges with reduced accuracy for thicker specimens and for thermal conductivity values up to 60 $W·m^{-1}·K^{-1}$.

NOTE 1—A body is considered homogeneous when the property to be measured is found to be independent of specimen dimensions.

1.2 This test method is similar in concept to Test Method C518, but is modified to accommodate smaller test specimens, having a higher thermal conductance. In addition, significant attention has been paid to ensure that the thermal resistance of contacting surfaces is minimized and reproducible.

1.3 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this 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, health, and 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. Related Documents

2.1 *ASTM Standards:*[2]

C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus

## 3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *heat flux transducer (HFT), n*—a device that produces an electrical output that is a function of the heat flux, in a predefined and reproducible manner.

3.1.2 *thermal conductance (C), n*—the time rate of heat flux through a unit area of a body induced by unit temperature difference between the body surfaces.

3.1.2.1 *average temperature of a surface, n*—the area-weighted mean temperature of that surface.

3.1.2.2 *average (mean) temperature of a specimen (disc shaped), n*—the mean value of the upper and lower face temperatures.

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

3.1.3.1 *apparent thermal conductivity, n*—when other modes of heat transfer through a material are present in addition to conduction, the results of the measurements performed in accordance with this test method will represent the apparent or effective thermal conductivity for the material tested.

3.1.4 *thermal resistance (R), n*—the reciprocal of thermal conductance.

3.2 *Symbols:*

$\lambda$ = thermal conductivity, $W·m^{-1}·K^{-1}$
$C$ = thermal conductance, $W·m^{-2}·K^{-1}$
$R$ = thermal resistance, $m^2·K·W^{-1}$
$\Delta x$ = specimen thickness, mm



[1] This test method is under the jurisdiction of ASTM Committee E37 on Thermal Measurements and is the direct responsibility of Subcommittee E37.05 on Thermophysical Properties.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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

$A$ = specimen cross-sectional area, $m^2$
$Q$ = heat flow, W
$\varphi$ = heat flux transducer output, mV
$N$ = heat flux transducer calibration constant, $W \cdot m^{-2} \cdot mV^{-1}$
$N\varphi$ = heat flux, $W \cdot m^2$
$\Delta T$ = temperature difference, °C
$T_g$ = temperature of guard heater, °C
$T_u$ = temperature of upper heater, °C
$T_l$ = temperature of lower heater, °C
$T_1$ = temperature of one surface of the specimen, °C
$T_2$ = temperature of the other surface of the specimen, °C
$T_m$ = mean temperature of the specimen, °C
$_s$ = unknown specimen
$_r$ = known calibration or reference specimen
$_o$ = contacts

## 4. Summary of Test Method

4.1 A specimen and a heat flux transducer (HFT) are sandwiched between two flat plates controlled at different temperatures, within an insulated guard tube, to produce an uniform heat flow. A reproducible load is applied to the test stack by pneumatic or other means, to ensure that there is a reproducible contact resistance between the specimen and plate surfaces. A guard surrounds the test stack and is maintained at a uniform mean temperature of the two plates, in order to minimize lateral heat flow to and from the stack. On attaining steady state conditions, the difference in temperature between the surfaces contacting the specimen is measured with temperature sensors embedded in the plate surfaces, together with the electrical output of the HFT. This output (voltage) is proportional to the heat flow through the specimen, the HFT and the interfaces between the specimen and the apparatus. The proportionality is obtained through prior calibration of the system with specimens of known thermal resistance measured under the same conditions, such that contact resistance at the surfaces can be made reproducible.

## 5. Significance and Use

5.1 This test method describes a procedure to measure and compare the thermal resistance properties of specimens (less than 25 mm in thickness) under controlled conditions.

## 6. Apparatus

6.1 A schematic rendering of a typical apparatus is shown in Fig. 1. The position of the HFT relative to the specimen is not important (in may be on the hot or cold side) as the method is based on the maintenance of uniform axial heat flow with minimal radial heat loss or gains. It is up to the designer/user of the application to choose upward, downward, or horizontal heat flow, although downwards heat flow in a vertical stack is most commonly used.

6.2 *Key Components of a Typical Device* (The numbers 1 to 22 in parentheses refer to Fig. 1)*:*

6.2.1 The adjustable compressive force for the stack is to be provided by either a regulated pneumatic or hydraulic cylinder (1), dead weights or a spring loaded mechanism. In either case, means shall be provided to ensure that the loading can be varied and set to selected reproducible values.

6.2.2 The loading force shall be transmitted to the stack through a gimball joint (2) that allows up to 5° swivel in the plane perpendicular to the axis of the stack.

6.2.3 A suitable insulator plate (3) separates the gimball joint from the upper plate (4).



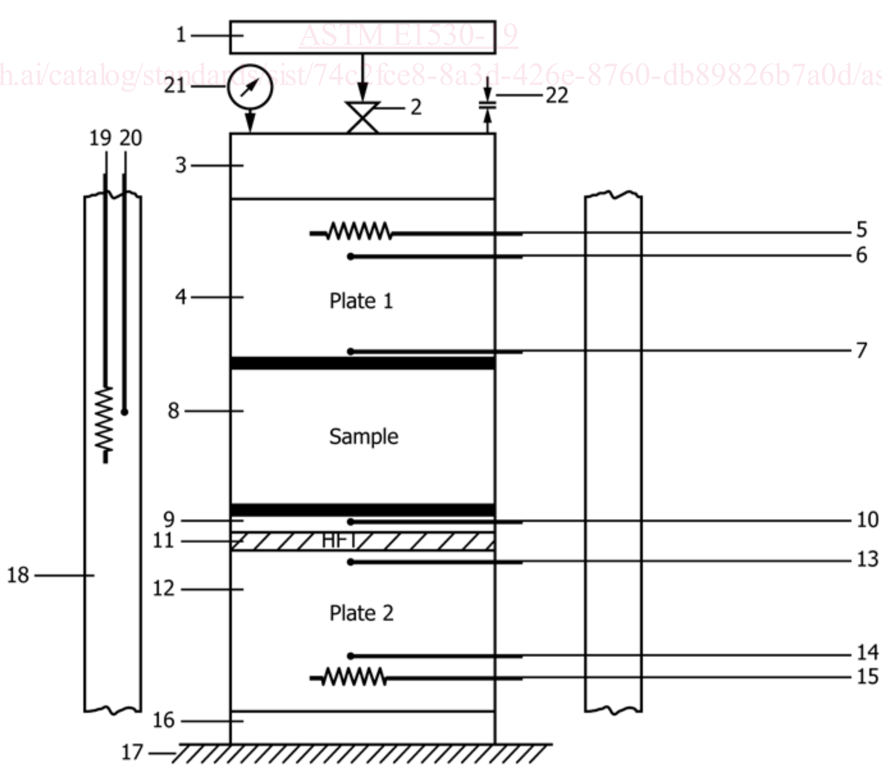


FIG. 1 Key Components of a Typical Device

6.2.4 The upper plate (assumed to be the hot plate for the purposes of this description) is equipped with a heater (5) and control temperature sensor (6) adjacent to the heater, to maintain the desired temperature. (Other means of producing and maintaining temperature may also be used providing the requirements in 6.3 are met.) The construction of the upper plate is such as to ensure uniform heat distribution across the face in contact with the specimen (8). A temperature sensor (7) that defines the temperature of the interface on the plate side is attached to this face (or embedded in close proximity to it) such that it does not interfere with the specimen/plate interface.

6.2.5 The specimen (8) is in direct contact with the upper plate on one side and an intermediate plate (9) on the other side.

6.2.6 The intermediate plate (9) is an optional item. Its purpose is to provide a highly conductive environment to the second temperature sensor (10), to obtain an average temperature of the surface. If the temperature sensor (10) is embedded into the face of the HFT, or other means are provided to define the temperature of the surface facing the specimen, the use of the intermediate plate is not mandatory.

6.2.7 The heat flux transducer (HFT) is a device that will generate an electrical signal in proportion to the heat flux across it. The level of output required (sensitivity) significantly depends on the rest of the instrumentation used for its evaluation. The overall performance of the HFT and its readout instrumentation shall be such as to meet the requirements in Section 13.

6.2.8 The lower plate (12) is constructed similarly to the upper plate (4), except it is positioned as the mirror image. Both plates shall have a uniform thickness with the surfaces in contact with the specimen being flat and parallel and having a surface roughness of less than 10 µm maximum.

6.2.9 An insulator plate (16) separates the lower plate (12) from the heat sink (17). In case of using circulating fluid in place of a heater/temperature sensor arrangement in the upper or lower plates, or both, the heat sink may or may not be present.

6.2.10 The entire stack is surrounded by a guard tube, insulated from heat losses to the outside, with a cross section that is not too different from that of the stacks (18) equipped with a heater or cooling coils (19), or both, and a similar control temperature sensor (20) to maintain it at the mean temperature between the upper and lower plates. A small, generally unfilled, gap separates the guard from the stack. For instruments limited to operate in the ambient region, no guard is necessary although the use of a draft shield is recommended.

NOTE 2—For materials in the higher thermal conductivity range, in particular, it is permissible to use a very thin layer of a suitable high conductivity contact medium on the contacting surfaces of the specimen to further reduce the thermal resistance of the interface and promote uniform thermal contact across the interface area. Calibration shall be performed under similar conditions of use or non-use of the contact medium.

NOTE 3—Useful information on interfacial materials used for this test method is available from literature.[3]

NOTE 4—The cross-sectional area and the shape of the specimen can be any, however, circular and rectangular cross sections are most commonly used. Minimum size is dictated by the magnitude of the disturbance caused by thermal sensors in relation to the overall flux distribution. The most common sizes are 25 mm and 50 mm disks.

6.2.11 The measurement system is preferably equipped with suitable means (21) to measure the in situ thickness of the specimen and provide a means (22) to limit compression when testing soft materials.

NOTE 5—This requirement is also mandatory for testing materials that soften while heated.

6.3 *Requirements:*

6.3.1 Temperature control of upper and lower plate is to be ±0.1°C or better.

6.3.2 Reproducible load of 0.28 MPa has been found to be satisfactory for solid specimens. The minimum load shall not be less than 0.07 MPa.

6.3.3 Temperature sensors are usually fine gage or small-diameter sheath thermocouples, however, ultraminiature resistance thermometers and linear thermistors may also be used.

6.3.4 Operating range of a device using a mean temperature guard shall be limited to from −100 °C to 300 °C, when using thermocouples as temperature sensors, and from −180 °C to 300 °C when platinum resistance thermometers are used. Thermistors are normally present on more restricted allowable temperature range of use.

## 7. Sampling and Conditioning

7.1 Cut representative test specimens from larger pieces of the sample material or body.

7.2 Condition the cut specimens in accordance with the requirements of the appropriate material specifications, if any.

## 8. Test Specimen

8.1 The specimen to be tested should be representative for the sample material. The recommended specimen configurations of 25 mm or 50 mm ± 0.25 mm diameter disks or squares, shall have smooth flat and parallel surfaces, having a finish of 10 µm or less where possible, such that a uniform thickness within ±0.025 mm is attained in the range from 0.5 mm to 25.4 mm For testing specimens having a thickness less than 0.5 mm, an alternative technique, described in Annex A1, is required.

## 9. Calibration

9.1 Calibration of the system shall be undertaken using a set of reference specimens having a range of thermal resistance achieved using different materials of known thermal conductivity or using different thickness of the same materials.

NOTE 6—At this writing (2017), there is a very limited number of appropriate reference materials available. Comprehensive information,

[3] Stacey, C., Sumpkin, A. J., and Jarrett, R. N., "Techniques for Reducing Thermal Contact Resistance in Steady-State Thermal Conductivity Measurements on Polymer Composites," *International Journal of Thermophysics*, Vol 37, 2016, p. 107.

**TABLE 1 Typical Thermal Resistance Values of Specimens of Different Materials**

| Material | Approximate Thermal Conductivity, $W \cdot m^{-1} \cdot K^{-1}$ at 30 °C | Thickness, mm | Approximate Thermal Resistance, $(cm)^2 \cdot K \cdot W^{-1}$ at 30 °C |
|---|---|---|---|
| Vespel[A] Polyimide SP1 | 0.4 | 20 | 500 |
| Vespel[A] Polyimide SP1 | 0.4 | 10 | 250 |
| Vespel[A] Polyimide SP1 | 0.4 | 1 | 25 |
| Polyethylene | 0.2 | 1 | 50 |
| Polyethylene | 0.2 | 0.5 | 25 |
| Polyethylene | 0.2 | 0.1 | 5 |
| Pyroceram 9606[B] | 4 | 20 | 50 |
| Pyroceram 9606[B] | 4 | 10 | 25 |
| Pyrex 7740[B] Glass | 1 | 20 | 200 |
| Pyrex 7740[B] Glass | 1 | 10 | 100 |
| Pyrex 7740[B] Glass | 1 | 1 | 10 |
| 304 Stainless Steel | 14 | 20 | 14 |
| 304 Stainless Steel | 14 | 10 | 7 |

[A] Vespel is a product and trademark of DuPont, Wilmington, DE.
[B] Pyrex 7740 and Pyroceram 9606 are products and trademarks of Corning Glass Co.

**TABLE 2 Thermal Conductivity Values of Selected Reference Materials**

| Temperature (°C) | Thermal Conductivity $(W \cdot m^{-1} \cdot K^{-1})$ | | |
|---|---|---|---|
| | Vespel[A] SP1 | Pyrex 7740[B] | Pyroceram 9696[C] |
| –50 | ... | 1.010 | ... |
| 0 | ... | 1.104 | ... |
| 25 | 0.377 | 1.177 | 4.06 |
| 100 | 0.391 | 1.236 | 3.71 |
| 200 | 0.413 | 1.330 | 3.42 |
| 300 | 0.436 | 1.447[D] | 3.23 |
| 400 | ... | ... | 3.10 |
| 500 | ... | ... | 3.00 |
| 600 | ... | ... | 2.92 |
| 700 | ... | ... | 2.86 |
| 800 | ... | ... | 2.81 |
| 900 | ... | ... | 2.77 |
| 1000 | ... | ... | 2.71 |

[A] Jacobs-Fedore, R. A., and Stroe, D. E., "Thermophysical Properties of Vespel SP1," in *Thermal Conductivity 27: Thermal Expansion 15*, DEStech Publications, Lancaster, PA, 2004, pp. 231–238.
[B] Tye, R. P., Hume, D., "Reference Materials for Thermal Transport Property Measurements," *Journal of Thermal Analysis and Calorimetry*, 2017, pp. 1–11.
[C] Salmon, D., Roebben, G., Lamberty, A., Brandt, R., "Certification of Thermal Conductivity and Thermal Diffusivity Up to 1025 K of a Glass-Ceramic Reference Material BCR-724," EUR Report 21764 EN, European Commission, Geel, Belgium, 2007.
[D] Powell, R. W., Ho, C. Y., and Liley, P. E., *Thermal Conductivity of Selected Materials*, Special Publication NSRDS, National Bureau of Standards, Washington, DC 1966.

**TABLE 3 Thermal Conductivity Values of Selected Reference Materials[A,B]**

| Temperature (°C) | Thermal Conductivity $(W \cdot m^{-1} \cdot K^{-1})$ | | | |
|---|---|---|---|---|
| | 310 Stainless Steel | 430 Stainless Steel | Inconel 600 | Nimonic 75 |
| 50 | 13.2 | 20.9 | 13.3 | 12.8 |
| 100 | 14.1 | 21.6 | 14.2 | 13.7 |
| 200 | 15.9 | 22.8 | 15.9 | 15.4 |
| 300 | 17.7 | 23.8 | 17.8 | 17.2 |
| 400 | 19.5 | 24.5 | 19.7 | 19.1 |
| 500 | 21.2 | 24.9 | 21.7 | 21.1 |
| 600 | 23.0 | 25.1 | 23.7 | 23.1 |
| 700 | 24.8 | 25.9 | 25.8 | 25.2 |
| 750 | 25.7 | 26.4 | 26.9 | 26.2 |

[A] Clark, J., and Tye, R., "Thermophysical Properties Reference Data for Some Key Engineering Alloys," *High Temperatures – High Pressures*, Vol 35/36, 2003/2004, pp. 1–14.
[B] Tye, R. P., and Salmon, D. R, "Development of New Thermal Conductivity Reference Materials: A Summary of Recent Contributions by National Physical Laboratory," in *Thermal Conductivity 27: Thermal Expansion 15*, DEStech Publications, Lancaster, PA, 2004, pp. 372–381.



including source, description, material type, range of application, availability, and properties is available.[4]

9.2 Table 1 contains a list of several available materials commonly used for calibration together with corresponding thermal resistance ($R_s$) values for a given thickness. This information is provided to assist the user in selecting optimum specimen thickness for testing a material and in deciding which calibration specimens to use.

9.3 The range of thermal conductivity for which the test method is most suitable is such that the optimum thermal resistance range is from 10 $(cm)^2 \cdot K \cdot W^{-1}$ to 400 $(cm)^2 \cdot K \cdot W^{-1}$. The most commonly recommended and used materials for calibration are Pyrex 7740[5] (a glass) and Pyroceram 96063[5] (a ceramic), Vespel[6] (a polyimide, a polymer), polymethylmethacrylate (PMMA, a polymer), and one of several stainless steel (a metal).

9.4 Table 2 and Table 3 list thermal conductivity values for selected reference materials. Their temperature range of application, in some cases, exceeds the applicable temperature range for this test method but the information is considered useful for the general user.

## 10. Procedure

10.1 Select the mean temperature conditions required. Adjust the upper and lower heaters such that the temperature difference at the required mean temperature is on the order of 30 °C to 35 °C and that across the specimen is not less than 3 °C. Adjust the guard temperature to the average of the upper and lower heaters.

[4] Tye, R. P., and Hume, D.,"Reference Materials for Thermal Transport Property Measurements," *Journal of Thermal Analysis and Calorimetry*, 2017, pp. 1–11.

[5] Pyrex 7740 and Pyroceram 9606 are products and trademarks of Corning Glass Co.

[6] Vespel SP1 is a product and trademark of DuPont, Wilmington, DE.