Designation: C1919 – 22

Standard Practice for
Measurement of the Steady-State Thermal Transmission Properties of Small Specimens Using the Heat Flow Meter Apparatus[1]

1. Scope

1.1 This practice covers the measurement of steady state thermal transmission properties of the small flat slab thermal insulation specimen using a heat-flow-meter apparatus.

1.2 This practice provides a supplemental procedure for use in conjunction with Test Method C518 for testing a small specimen. This practice is limited to only small specimens and, in all other particulars, the requirements of Test Method C518 apply.

1.3 This practice characterizes small specimens having lateral dimensions less than the lateral dimensions of the heat flux transducer used to measure the heat flow. The procedure in Test Method C518 shall be used for specimens having lateral dimensions equal to or larger than the lateral dimensions of the heat flux transducer.

NOTE 1—The lower limit for specimen size is typically determined by the user for their particular material. As an example, Ref. (**1**)[2] established a lower limit for specimen dimensions of 0.1 m by 0.1 m for several different thermal insulation materials for a 0.3 m by 0.3 m heat-flow-meter apparatus having a heat flux transducer 0.15 m by 0.15 m.

1.4 This practice is intended only for research purposes, in particular, when larger specimens are unavailable. This practice shall not be used in conjunction with Test Method C518 for certification testing of products; compliance with ASTM Specifications; or compliance with regulatory or building code requirements.

1.5 The values stated in SI units are to be regarded as the standard. No other units of measurement are included in this practice.

1.6 *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.*

1.7 *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:*[3]

C168 Terminology Relating to Thermal Insulation
C518 Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus
C1045 Practice for Calculating Thermal Transmission Properties Under Steady-State Conditions

3. Terminology

3.1 *Definitions*—For definitions of terms and symbols used in this test method, refer to Terminology C168 and to the following subsections.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *mask, n*—the mask is a uniform thermal insulation (for example, medium density foam ($\approx 25 \pm 10$ kg/m^3), aerogel etc.) having stable structural and thermal properties that covers the entire heat-flow-meter plate area with a central section cut out representing the area covered by the specimen (see Fig. 1).

3.3 *Symbols and Units*—The symbols used in this test method have the following significance:

3.3.1 λ_a—apparent thermal conductivity, W/(m·K).
3.3.2 C—thermal conductance, W/(m^2·K).
3.3.3 R—thermal resistance, (m^2·K)/W.
3.3.4 R_m—mask thermal resistance, (m^2·K)/W.
3.3.5 Q—heat flow determined from Test Method C518, W.
3.3.6 Q_s—heat flow through the specimen area A_s, W.
3.3.7 Q_m—heat flow through the mask area A_m, W.

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[1] This practice is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

Current edition approved Dec. 1, 2022. Published January 2023. DOI: 10.1520/C1919-22.

[2] The boldface numbers in parentheses refer to the list of references at the end of this standard.

[3] 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.

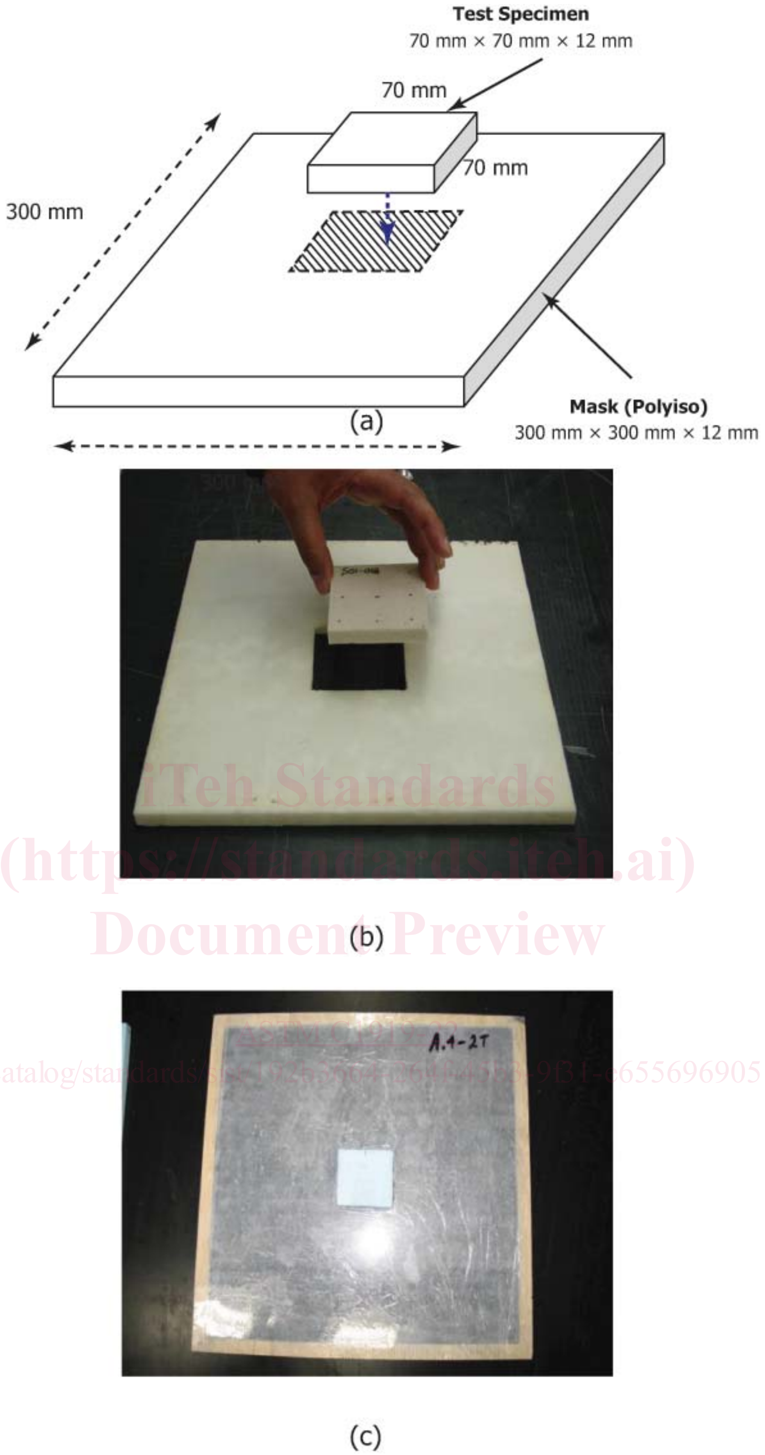

FIG. 1 (a) Typical set up for thermal conductivity measurement of specimens smaller than the heat flux transducer, (b) photo of a test specimen with a foam mask, (c) photo depicts a test specimen of extruded polystyrene surrounded by a mask of aerogel. A wooden frame is installed around the perimeter of the mask to prevent the mask and specimen from being compressed. The entire assembly (mask and specimen) is wrapped in a polyethylene film to facilitate handling.

3.3.8 Q_{per}—heat flow through perimeter edge between specimen and mask, W.

3.3.9 *A*—area corresponding to the heat flux transducer (that is, metering area), m^2.

3.3.10 A_s—specimen area, m^2.

3.3.11 A_m—mask area, m^2.

3.3.12 ΔT—temperature difference across the specimen, K.

3.4 *Subscripts:*

3.4.1 *s*—specimen.

3.4.2 *m*—mask.

3.4.3 *per*—perimeter edge between specimen and mask.

4. Summary of Practice

4.1 This practice provides guidance on the impact of specimen size, thickness, thermal conductance, and surrounding mask material of thermal insulation, on the uncertainty of the measurement when using a heat-flow meter apparatus to determine the thermal transmission properties of specimens that are smaller in area than that of the heat flux transducer contained in the apparatus.

4.2 The practice evaluates the impact of testing specimens smaller than the heat flux transducer (HFT) and to assess the relative importance of having a surrounding mask. The mask material shall be thermally stable, homogeneous, and have a thermal conductivity and texture as close as possible to the specimen being tested. The mask surrounds the test specimen and provides a uniform, reproducible heat flow pattern at the edges of the metering area perimeter.

4.3 This practice provides a procedure for the determination of the steady-state heat flow through a small specimen, Q_s, by determination of the measured heat flow, Q, and related heat flows through the surrounding mask area, Q_m, and through the perimeter edge between the specimen and mask, Q_{per}.

4.4 The measurement result, Q_s, obtained from this practice is intended to be used with Test Method C518 and Practice C1045 to determine steady-state thermal transmission properties of the small specimen.

5. Significance and Use

5.1 Thermal conductivity measurements on small insulation specimens are important during new product development processes or when larger specimens cannot be collected during forensic investigation (that is, failure analysis) (**1, 2**).

5.2 Numerous research projects have recently been initiated to develop insulation materials that have very high thermal resistivities (greater than 83 (m K)/W). Projects ranging from coatings to improve the thermal performance of single pane/layer glazing systems to the development of novel insulation products for building envelopes are being undertaken (**1-4**). All these projects have struggled in the development of new material technologies due to the difficulty associated with the measurement of thermal conductivity of small sections (approximately 0.025 m by 0.025 m) of high thermal resistance materials. As new materials are being developed, the size of each test specimen impacts the cost of development. Most of the existing test equipment and the methods do not align with the researcher's need; the equipment requires a large specimen size is time consuming, and expensive to produce.

5.3 This practice provides a standardized procedure to enable the thermal characterization of small specimens of insulation materials. Accurate, and reliable thermal metrology to assess thermal properties of new insulation materials, such as novel very low thermal conductivity (< 0.01 W/ (m K)) nanomaterials or bio-based foam insulations, in small material sample sections, and minimal data analysis requirements is the desired outcome of this practice.

5.4 The ratio of the area of the specimen and the heat flux transducer has a significant impact on the uncertainty of the results obtained from this practice. As the specimen area decreases this ratio decreases, a smaller percentage of the total heat flow is associated with the unknown specimen. Information from the literature (**4**) shows that some heat-flow-meter apparatus, generally not available commercially and used by the research laboratories only, can be modified to change out the heat flux transducer so that transducers of varying sizes can be deployed. The observations presented in Fig. 2 were obtained from the measurements done by such a heat-flow-meter apparatus that was modified to change out the heat flux transducer. Fig. 2 demonstrates the significance of the ratio of

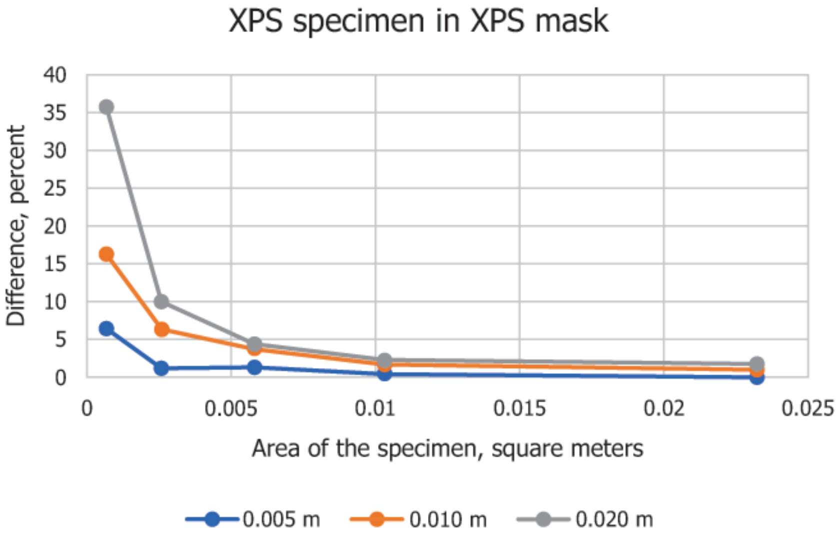

FIG. 2 Example of a data set obtained from 0.010 m^2 (that is, 0.10 m × 0.10 m) heat flux transducer (heat flow) exploring the uncertainty (that is, difference between full size XPS specimen and smaller XPS specimen placed inside the mask) of varying thicknesses, 0.005 m, 0.010 m, and 0.020 m

the area of the specimen and the heat flux transducer on the accuracy of the thermal conductivity measurement using this Practice. This exercise is not a required part of this Practice and Fig. 2 is for information only.

6. Procedure

6.1 Select a rigid or semi-rigid material for the mask having a low thermal conductance. Prepare the mask to have the same lateral dimensions as the apparatus plate size and the same thickness as the small test specimen.

NOTE 2—Acceptable mask materials are aged cellular polystyrene, aerogel, fiberglass, or other similar type material.

6.2 Determine the steady-state thermal transmission properties of the mask over the temperature range of interest following the procedure in Test Method C518.

6.3 Cut a central aperture from the mask to accommodate the small test specimen as shown in Fig. 1.

6.4 Determine Q_{per}, the flanking heat flow at the interface of the mask and specimen, over the temperature range of interest experimentally, using Test Method C518 with modifications described in 6.4.1 through 6.4.7. This is the preferred approach. An alternative procedure is to employ simulations to determine Q_{per}. A summary of the process is described in Annex A1.

6.4.1 Select a rigid or semi-rigid material for the surrogate specimen having a low thermal conductivity. Prepare the surrogate specimen to have the same lateral dimensions as the apparatus plate size and the same thickness as the small test specimen.

NOTE 3—An acceptable surrogate specimen material ideally has the same or similar thermal conductivity as the unknown test specimen. An iterative approach for selection of the surrogate material may be necessary to reduce the measurement uncertainty.

6.4.2 Determine the steady-state thermal transmission properties of the surrogate specimen over the temperature range of interest following the procedure in Test Method C518.

6.4.3 Prepare the small surrogate specimen by cutting a centrally located sample to fit securely in the mask aperture as shown in Fig. 1.

6.4.4 Determine the steady-state heat flow of the composite specimen (that is, mask with small surrogate specimen) over the temperature range of interest following the procedure in Test Method C518.

NOTE 4—The measured quantity, Q, obtained from Test Method C518 includes contributing heat flows through the mask (Q_m), small specimen (Q_s), and perimeter interface between the mask and small surrogate specimen (Q_{per}).

6.4.5 Compute the area-weighted thermal conductivity of the composite specimen assuming parallel heat flow paths in the mask and surrogate specimen. Calculate the corresponding heat flow using the area-weighted thermal conductivity.

6.4.6 Estimate Q_{per}, the mask-specimen interfacial heat flow from the difference of the measured quantity Q in 6.4.4 and the calculated heat flow in 6.4.5.

6.4.7 For more accurate results, determine Q_{per} for a variety of surrogate materials purposely selected to have mismatched thermal conductivity with the mask material.

NOTE 5—Experience has shown that thermal conductivity ratios of surrogate material to mask material of 0.33, 0.25, and 0.17 are recommended. The resulting data are curve-fit to predict Q_{per} as function of the thermal conductivity ratio.

6.5 Replace the surrogate small specimen in the mask with the unknown small test specimen.

6.6 Determine the steady-state heat flow of the composite specimen (that is, mask with unknown small test specimen) over the temperature range of interest following the procedure in Test Method C518.

6.7 Calculate Q_s, the heat flow through the small test specimen, from the difference of the measured quantity Q in 6.6 and the heat flow through the mask Q_m determined in 6.2 and perimeter interface heat flow Q_{per} determined in 6.4.

6.8 Use the results from 6.7 with Test Method C518 and Practice C1045 to determine the steady-state thermal transmission properties of the small test specimen.

7. Calculation

7.1 Calculate A_m, the area of the mask (m^2), as follows:

$$A_m = A - A_s \tag{1}$$

where:

A and A_s = the lateral surface areas (m^2) corresponding to the heat flux transducer and the small specimen, respectively.

7.2 Calculate λ_c, the area-weighted average thermal conductivity of the composite specimen (W/m·K), as follows:

$$\lambda_c = (\lambda_m A_m + \lambda_s A_s) / A \tag{2}$$

where:

λ_m and λ_s = the thermal conductivities (W/m·K) of the mask and small specimen, respectively.

7.3 Calculate Q_{per} or Q_s (W) as follows:

$$Q_{per} = Q - Q_m - Q_s \tag{3}$$

$$Q_s = Q - Q_m - Q_{per} \tag{4}$$

where:

Q_{per} = the flanking heat flow at the interface of the mask and small test specimen, W,
Q = the heat flow determined from Test Method C518, W,
Q_s = the heat flow normal to the small test specimen, W, and
Q_m = the heat flow normal to the mask corresponding to the area encompassed by the apparatus heat flux transducer, W.

7.4 Alternatively, calculate Q_{per} from the computer simulations described in Annex A1.

7.5 Calculate the steady-state thermal transmission properties, C, R, λ, and r for the test specimen following the procedures in Test Method C518 and Practice C1045.

8. Report

8.1 All the requirements of Test Method C518 shall be included in the reporting, excluding the sections related to regulatory certifications and compliances.