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Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus¹

This standard is issued under the fixed designation C 518; 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 that has been adopted by the Department of Defense.

INTRODUCTION

This test method presents a comprehensive assemblage of information and requirements on the complex problem of the measurement of the thermal transmission properties of insulations using a heat flow meter apparatus. For convenience, it is organized in four major parts:

- General Considerations (Sections 1 through 6)
- Apparatus and Calibration (Sections 7 through 9)
- Test Procedures and Report (Sections 10 through 14)
- Annexes (A1 through A4)

This test method shall be used in conjunction with Practice C 1045.

Many advances have been made in thermal insulation technology, both in measurement techniques and in improved understanding of the principles of heat flow through such materials. These advances have prompted revisions in the conceptual approaches to the measurement of the thermal transmission properties, see References (1), (2), (3), and (4).² All users of this test method should be aware of these concepts.

1. Scope

1.1 This test method covers the measurement of steady state thermal transmission through flat slab specimens using a heat flow meter apparatus.

1.2 This is a comparative (or secondary) method of measurement since specimens of known thermal transmission properties must be used to calibrate the apparatus. Properties of the calibration specimens must be traceable to an absolute measurement method, and should be obtained from or traceable to a recognized national standards laboratory.

1.3 The test method is applicable to the measurement of thermal transmission through a wide range of specimen properties and environmental conditions. The method has been used at ambient conditions of 10 to 40°C with thicknesses up to approximately 250 mm, and with plate temperatures from –195°C to 540°C at 25 mm thickness (Refs. (5, 6)).

1.4 This test method may be used to characterize material properties which may or may not be representative of actual conditions of use. Other test methods such as Test Methods C 236 or C 976 should be used if needed.

1.5 To meet the requirements of this test method the

thermal resistance of the sample must be greater than 0.10 K·m²/W in all directions.

1.6 It is not practical in a test method of this type to try to establish details of construction and procedures to cover all contingencies that might offer difficulties to a person without pertinent technical knowledge. Thus users of this test method shall have sufficient knowledge to satisfactorily fulfill their needs. For example, knowledge of heat transfer principles, low level electrical measurements, and general test procedures is required.

1.7 Standardization of this test method is not intended to restrict in any way the future development of improved or new methods or procedures by research workers.

1.8 Since the design of a heat meter apparatus is not a simple matter, a procedure for qualifying an apparatus is given in 7.8.

1.9 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

C 167 Test Methods for Thickness and Density of Blanket or Batt Thermal Insulations³

¹ This test method is under the jurisdiction of ASTM Committee C-16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.30 on Thermal Measurement.

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² The boldface numbers in parentheses refer to the list of references at the end of this test method.

³ Annual Book of ASTM Standards, Vol 04.06.



- C 168 Terminology Relating to Thermal Insulating Materials³
- C 177 Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties By Means of the Guarded Hot Plate Apparatus³
- C 236 Test Method for Steady-State Thermal Performance of Building Assemblies by Means of a Guarded Hot Box³
- C 519 Test Method for Density of Fibrous Loose-Fill Building Insulations³
- C 687 Practice for Determination of the Thermal Resistance of Loose-Fill Building Insulation³
- C 976 Test Method for Thermal Performance of Building Assemblies by Means of a Calibrated Hot Box³
- C 1045 Practice for Calculating Thermal Transmission Properties from Steady-State Heat Flux Measurements³
- C 1132 Practice for Calibration of the Heat Flow Meter Apparatus³
- E 230 Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples⁴
- E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method⁵

3. Terminology

3.1 *Definitions*—The terms and symbols are as defined in Definitions C 168 with exceptions included as appropriate.

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

- λ = thermal conductivity, W/m·K,
- C = thermal conductance, W/m²·K,
- R = thermal resistance, m²·K/W,
- q = heat flux, W/m²,
- Q = heat flow, W,
- A = area measured on a selected isothermal surface, m²,
- L = thickness of specimen measured along a path normal to isothermal surfaces, m,
- T_m = mean temperature, K,
- ΔT = temperature difference, K,
- ρ = density of the material as tested, kg/m³,
- S = sensitivity of heat flow transducer (W/m²)/V,
- E = heat flow transducer output, V,
- T_h = temperature of hot plate surface, K, and
- T_c = temperature of cold plate surface, K.

4. Summary of Test Method

4.1 The heat flow meter apparatus establishes steady state unidirectional heat flux through a test specimen between two parallel plates at constant but different temperatures. By appropriate calibration of the heat flux transducer(s) with calibration standards and by measurement of the plate temperatures and plate separation, Fourier's law of heat conduction is used to calculate thermal conductivity, thermal resistance, or resistivity.

4.2 The accurate use of the test method is limited by the capability of the apparatus to reproduce unidirectional constant heat flux density in the specimens, and by the precision in the measurement of temperature, thickness,

EMF produced by heat flux transducer, etc.

5. Significance and Use

5.1 This test method provides a rapid means of determining thermal properties with high precision and as such is useful in research and quality control work.

5.2 The thermal transmission properties of specimens of a given material or product may: (1) vary due to variability of the composition of the material; (2) be affected by moisture or other conditions; (3) change with time; (4) change with mean temperature and temperature difference, and (5) depend upon the prior thermal history. It must be recognized, therefore, that the selection of typical values of thermal transmission properties representative of a material in a particular application should be based on a consideration of these factors and will not necessarily apply without modification to all service conditions. As an example, this test method provides that the thermal properties shall be obtained on specimens that do not contain any free moisture although in service such conditions may not be realized. Even more basic is the dependence of the thermal properties on variables such as mean temperature and temperature difference. These dependencies should be measured or the test made at conditions typical of use.

5.3 Special care must be taken in the measurement procedure for specimens exhibiting appreciable inhomogeneities, anisotropies, rigidity, or especially high or low resistance to heat flow (see Practice C 1045). Special considerations are necessary when the measurements are conducted at either high or low temperatures, in a vacuum or in hazardous gases.

5.4 The determination of the accuracy of the method for any given test is a function of the apparatus design, of the related instrumentation and of the type of specimens under test (see Section 9), but this method is capable of determining thermal transmission properties within $\pm 2\%$ of those determined by Test Method C 177 when the ambient temperature is near the mean temperature of the test ($T(\text{ambient}) = T(\text{mean}) \pm 1^\circ\text{C}$), and in the range of 10 to 40°C.

5.4.1 Where certification of measurement by this test method is required, the apparatus shall have the capabilities required in 7.8 and one of the following procedures must be followed:

5.4.1.1 The testing laboratory apparatus shall be calibrated within 24 h before or after the certification test using calibration standards that have been issued or whose values have been established by a recognized National Standards Laboratory not more than five years prior to the certification date. The average of two calibrations shall be used as the calibration factor and the specimen(s) certified with this average value. When the change in calibration factor is greater than one percent, the standard specimen shall be retested and a new average calculated. If the change in calibration factor is still greater than 1 % the apparatus must be calibrated using the procedure in Section 8.

5.4.1.2 Where both the short and long term stabilities of the apparatus have been proven to be better than 1 % of the reading, see 8.4, the apparatus may be calibrated at less frequent intervals, not exceeding 30 days. The specimens so tested cannot be certified until after the calibration following the test and then only if the change in calibration factor from

⁴ Annual Book of ASTM Standards, Vol 14.03.

⁵ Annual Book of ASTM Standards, Vol 14.02.

the previous calibration test is less than 1 %. When the change in calibration is greater than one percent, test results from this interval shall be considered void and the tests repeated in accordance with 5.4.1.1.

5.4.2 The precision (repeatability) of measurements made by the heat flow meter apparatus calibrated as in 5.4.1 are normally much better than ± 1 % of the mean value. This precision is required to identify changes in calibration and is desirable in quality control applications.

6. Limitations to Test Method

6.1 Limitations Due to Apparatus:

6.1.1 The apparatus shall not be used at temperatures, thicknesses, or resistances, other than those within the range of the calibration, unless it can be shown that there is no difference in accuracy.

6.1.2 The apparatus must be capable of maintaining at least a 10°C temperature difference across the specimen for the duration of the test, unless a smaller ΔT is a requirement of a particular test.

6.2 Limitations Due to the Specimens:

6.2.1 The specimens under test may also limit the use of the test method and these limitations are outlined in Practice C 1045.

7. Apparatus

7.1 The construction details given in this section should be understood by the user of this test method. While it is mandatory that these details be carefully followed when constructing an apparatus, it behooves the user to verify that the equipment was built as specified. Serious errors of measurement may result from this oversight.

7.2 General:

7.2.1 The general features of a heat flow meter apparatus with the specimen or the specimens installed are discussed in Annex A1. A heat flow meter apparatus consists of two isothermal plate assemblies, one or more heat flux transducers, equipment to measure and control temperature, thickness, and the output of the heat flux transducers and equipment to control the environmental conditions when needed. Each configuration will yield equivalent results if used within the limitations stated in this test method. There are distinct advantages for each method in practice and these are discussed in Annex A1.

7.2.2 The working surfaces of the plates and the heat flux transducer (that is, the surfaces making contact with the specimens) shall be painted or otherwise treated to have a total hemispherical emittance of greater than 0.84 at operating temperatures (Note 1).

NOTE 1—Hard anodizing of aluminum produces a surface with a total hemispherical emittance of approximately 0.85. Several paints are available which when applied as directed, produce a total hemispherical emittance of approximately 0.86.

7.3 *Plate Assemblies, Hot and Cold*—The two plate assemblies provide isothermal surfaces in contact with either side of the test specimen. The assemblies consist of heat source or heat sink, a high conductivity surface, means to measure surface temperature, and means of support. A heat flux transducer may be attached to one, both or neither plate assembly, depending upon the design. In all cases the area defined by the dimensions of the heat flux transducer is

called the metering area and the remainder of the plate is the guard area.

7.3.1 The portion of each plate assembly in contact with the heat flux transducer, or if a heat flux transducer is not mounted on the plate assembly, the portion in contact with the sample, shall consist of a high conductivity material, usually metal, known as the isothermal plate. The isothermal plate shall be supported so as to minimize temperature gradients across its surface. For a 2 % total uncertainty, deviations from isothermal conditions over the plate surface of no more than ± 0.5 K shall be allowed.

7.3.2 A means shall be provided to maintain the temperature of the isothermal plates at the desired level. Examples are fluid baths, electrical heaters and combinations of these (see Refs (7, 8, 9)).

7.3.3 If a heat flux transducer is mounted at the midplane of the specimen then means shall be provided to determine the average temperature of the transducer in order to apply temperature corrections to the calibration, except when test temperatures are equal to those used in calibration, in which case no correction is required.

7.3.4 Means shall be provided to measure the temperature of the surfaces of the heat flux transducer or plates in contact with the specimen.

7.3.5 The surface plates shall be sufficiently rigid to maintain flatness and parallelism to within one-tenth the accuracy required of the final result. For measurements on non-rigid materials and an allowable total uncertainty of ± 2 %, a flatness and parallelism of 0.2 % of the maximum linear dimension of the heating unit is thus required (Note 2). One recommended way to check this is to generate a L-map over the metering area. This is discussed fully in Ref (10).

NOTE 2—The planeness of the surface can be checked with a straightedge, of a length greater than the width or diameter of the unit, held against the surface and viewed with a light behind the straightedge. Departures as small as $25\text{ }\mu\text{m}$ are readily visible, and larger departures can be measured using shimstock or thin paper.

7.3.5.1 The parallelism of the plates must be maintained for several reasons. In most cases it is the plate separation which is measured in order to determine specimen thickness. Furthermore the plate parallelism is important in maintaining consistent surface contact with specimens in repeat testing (such as calibration), and is required to maintain a uniform temperature difference across the specimen(s).

7.3.6 The rigidity, flatness, and parallelism of the plates may impede the testing of rigid specimens where it is not possible to obtain good surface contact. In such cases the use of a thin sheet of suitable homogeneous material may be interposed between the specimen and the plate surfaces. This thin sheet should have a low thermal resistance relative to the specimen. The resistance of the thin sheet should be determined using a Test Method C 177 apparatus. The resistance of the composite sandwich (sheet-rigid specimen-sheet) is then determined and the value of the sheet resistance (determined in a separate test) subtracted from the total resistance measured.

7.4 Temperature Measuring and Control Systems:

7.4.1 Any proven device possessing adequate accuracy may be used for measurement and control of the temperatures in the apparatus.