



Designation: D 5334 – 00

Standard Test Method for Determination of Thermal Conductivity of Soil and Soft Rock by Thermal Needle Probe Procedure¹

This standard is issued under the fixed designation D 5334; 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 presents a procedure for determining the thermal conductivity of soil and soft rock using a transient heat method. This test method is applicable for both undisturbed and remolded soil specimens as well as in situ and laboratory soft rock specimens. This test method is suitable only for isotropic materials.

1.2 This test method is applicable to dry materials over the temperature range from 20 to 100°C. It may be used over a limited range around ambient room temperatures for specimens containing moisture.

1.3 For satisfactory results in conformance with this test method, the principles governing the size, construction, and use of the apparatus described in this test method should be followed. If the results are to be reported as having been obtained by this test method, then all pertinent requirements prescribed in this test method shall be met.

1.4 It is not practicable in a test method of this type to aim to establish details of construction and procedure to cover all contingencies that might offer difficulties to a person without technical knowledge concerning the theory of heat flow, temperature measurement, and general testing practices. Standardization of this test method does not reduce the need for such technical knowledge. It is recognized also that it would be unwise, because of the standardization of this test method, to resist in any way the further development of improved or new methods or procedures by research workers.

1.5 The values stated in SI units are to be regarded as the standard. The inch-pound units given in parentheses are for information only.

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 and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 2216 Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock²

D 4439 Terminology for Geotextiles³

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *thermal epoxy*—any thermally conductive filled epoxy material having a value of $\lambda > 4 \text{ W}/(\text{m}\cdot\text{k})$.

3.1.2 *thermal grease*—any thermally conductivity grease having a value of $\lambda > 4 \text{ W}/(\text{m}\cdot\text{k})$.

3.2 *Symbols:*

3.2.1 E —measured voltage (V).

3.2.2 I —current flowing through heater wire (A).

3.2.3 L —length of heater wire (m).

3.2.4 λ —thermal conductivity [$\text{W}/(\text{m}\cdot\text{k})$].

3.2.5 Q —power consumption of heater wire in watts per unit length that is assumed to be the equivalent of heat output per unit length of wire.

3.2.6 R —total resistance of heater wire (Ω).

3.2.7 T_1 —initial temperature (k).

3.2.8 t_1 —initial time (s).

3.2.9 T_2 —final temperature (k).

3.2.10 t_2 —final time (s).

3.2.11 p_d —dry density (kg/m^3).

4. Summary of Test Method

4.1 The thermal conductivity is determined by a variation of the line source test method using a needle probe having a large length to diameter ratio to stimulate conditions for an infinitely long specimen. The probe consists of a heating element and a temperature measuring element and is inserted into the specimen. A known current and voltage is applied to the probe and the temperature rise with time noted over a period of time. The thermal conductivity is obtained from an analysis of the approximately linear portion of the quasi-steady-state temperature-time response.

5. Significance and Use

5.1 The thermal conductivity of both undisturbed and remolded soil specimens as well as in situ and laboratory soft

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² *Annual Book of ASTM Standards*, Vol 04.08.

³ *Annual Book of ASTM Standards*, Vol 04.09.

rock specimens is used to analyze and design systems used, for example, in underground transmission lines, oil and gas pipelines, radioactive waste disposal, and solar thermal storage facilities.

6. Apparatus

6.1 The apparatus shall consist of the following:

6.1.1 *Thermal Needle Probe*—A device that creates a linear heat source and incorporates a temperature measuring element (thermocouple or thermister) to measure the variation of temperature at a point along the line. The construction of a suitable device is described in Annex A1.

6.1.2 *Constant Current Source*—A device to produce a constant current.

6.1.3 *Thermal Readout Unit*—A device to produce a digital readout of temperature in degrees Celsius to the nearest 0.1K.

6.1.4 *Voltage-Ohm-Meter (VOM)*—A device to read voltage and current to the nearest 0.01 V and ampere.

6.1.5 *Timer*, stopwatch or similar time measuring instrument capable of measuring to the nearest 0.1 s for a minimum of 15 min.

6.1.6 *Equipment*, capable of drilling a straight vertical hole having a diameter as close as possible to that of the probe and to a depth at least equal to the length of the needle.

7. Specimen Preparation

7.1 *Undisturbed Specimens:*

7.1.1 *Thin-Walled Tube or Drive Specimens*—Cut a 200 ± 30 -mm (8.0 ± 1 -in.) long section of a sampling tube containing an undisturbed soil specimen. The tube section should have a minimum diameter of 51 mm (2.0 in.).

7.1.2 Weigh the specimen in a sampling tube or brass rings.

7.1.3 Insert the thermal needle probe into the specimen by either pushing the probe into a predrilled hole (dense specimen) to a depth equal to the length of the probe or pushing the probe into the specimen (loose specimen). Care should be taken to ensure that the thermal probe shaft is fully embedded in the specimen and not left partially exposed. (See Note 1.)

NOTE 1—To provide better thermal contact between the specimen and the probe, the probe may be coated with a thin layer of thermal grease. If a hole is predrilled for the needle probe, the diameter of the hole should be equal to or slightly less than the diameter of the needle probe to ensure a tight fit. A device, such as a drill press, may be used to insert the probe to ensure that the probe is inserted vertically and that no void spaces are formed between the specimen and the probe.

7.2 *Remolded Specimens:*

7.2.1 Compact the specimen to the desired density and water content (in a thin-walled metal or plastic tube) using an appropriate compaction technique. For further guidance on the effect of the various compaction techniques on thermal conductivity, refer to Mitchell et al. (1).⁴ The tube should have a minimum diameter of 51 mm (2.0 in.) and a length of 200 ± 30 mm (8.0 ± 1 in.).

7.2.2 Perform 7.1.2 and 7.1.3.

7.3 *Soft Rock Specimens:*

7.3.1 Specimen dimensions shall be no less than those of the calibration standard (8.3).

7.3.2 Insert the thermal needle probe into the specimen by predrilling a hole to a depth equal to the length of the probe. (See Note 1.)

8. Calibration

8.1 The thermal needle probe apparatus should be calibrated before its use. Perform calibration by comparing the experimental determination of the thermal conductivity of a standard material to its known value.

8.2 Conduct the test specified in Section 9 using a calibration standard as specified in 8.3.

8.3 *Calibration Standard*—One or more materials with known values of thermal conductivity in the range of the materials being measured (typically $0.2 < \lambda < 5$ W/m-K). Suitable materials include dry Ottawa sand, Pyrex 7740, Fused Silica and Pryoceram 9606 (2). The calibration standard shall be in the shape of a cylinder. The diameter of the cylinder shall be at least 40 mm and the length shall be at least 10 cm longer than the needle probe. A hole shall be drilled along the axis of the cylinder to a depth equal to the length of the probe. The diameter of the hole shall be equal to the diameter of the probe so that the probe fits tightly into the hole.

8.4 The measured thermal conductivity of the calibration specimen must agree within one standard deviation of the published value of thermal conductivity, or with the value of thermal conductivity determined by an independent method.

9. Procedure

9.1 For tests conducted in the laboratory, allow the specimen to come to equilibrium with room temperature.

9.2 Connect the heater wire of the thermal probe to the constant current source. (See Fig. 1.)

9.3 Connect the temperature measuring element leads to the readout unit.

9.4 Apply a known constant current (for example, equal to 1.0 A) to the heater wire such that the temperature change is less than 10 K in 1000 s.

9.5 Record the temperature readings at 0, 5, 10, 15, 30, 45, and 60 s, then take readings at 30-s time intervals for a minimum of 1000 s.

9.6 Turn off the constant current source.

9.7 Plot the temperature data as a function of time on a semilog graph. (See Fig. 2)

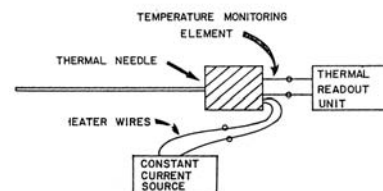


FIG. 1 Thermal Probe Experimental Setup

⁴ The boldface numbers given in parentheses refer to a list of references at the end of the standard.

THERMAL CONDUCTIVITY TEST

Tested by _____ Date _____
 Project Name _____ Compacted by _____ Date _____
 Project Number _____ Checked by _____ Date _____
 Boring Number _____ Checked by _____ Date _____
 Depth (meters) _____

Specimen Description _____
 Sample Description _____

Test Conditioning

A Thermal Needle _____
 B Current (Amp) _____

C How was needle inserted into sample?
 Pushed
 Pre-drilled

Specimen Conditions

Dry Density _____ KN/m³
 Initial Moisture Content _____ %
 Thermal Conductivity _____ [w/(m³ K)]

Remarks _____

Time	Elapsed Time (sec)	Thermocouple Reading (C°)

FIG. 2 Typical Experimental Test Results Plotted on Semilog Graph

ASTM D5334-00

9.8 Select linear portion of curve (pseudo steady state portion) and draw a straight line through the points. (See Fig. 3.)

9.9 Select times t_1 and t_2 at appropriate points on the line and read the corresponding temperatures T_1 and T_2 .

9.10 Perform an initial moisture content test method (see Test Method D 2216) and a dry density test method (see Test Method D 4439) on a representative specimen of the sample.

10. Calculation

10.1 Compute the thermal conductivity (λ) of the specimen from the linear portion of the experimental curve shown in Fig. 3 using the following relationship:

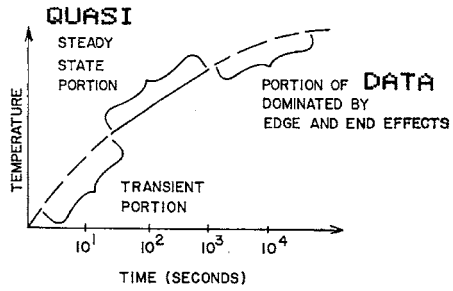
$$\lambda = \frac{2.30 Q}{4\pi(T_2 - T_1)} \text{Log}_{10}(t_2/t_1) = \frac{Q}{4\pi(T_2 - T_1)} \ln(t_2/t_1) \quad (1)$$

where:
 $Q =$ heat input $= \frac{I^2 R}{L} = \frac{EI}{L}$

10.2 Derivation of Eq 1 is presented by Carslaw and Jaeger (3), and adapted to soils by VanRooyen and Winterkorn (4); VanHerzen and Maxwell (5); and Winterkorn (6).

11. Report

- 11.1 For each thermal conductivity test, fill out a data sheet similar to that shown in Fig. 4, reporting the following:
 - 11.1.1 Date of the test and project name or number,
 - 11.1.2 Boring number, sample or tube number, sample depth, and data recorded in 9.5.
 - 11.1.3 Initial moisture content and dry density,
 - 11.1.4 Time versus temperature plot (see Fig. 3),
 - 11.1.5 Thermal conductivity, and



A) IDEALIZED CURVE

FIG. 3 Typical Experimental Test Results Plotted on Semilog Graph