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Plastics — Determination of thermal conductivity and thermal diffusivity —

Part 2:
Transient plane heat source (hot disc) method

Plastiques — Détermination de la conductivité thermique et de la diffusivité thermique —

Partie 2: Méthode de la source plane transitoire (disque chaud)

Reference number
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Foreword

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This document was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 5, *Physical-chemical properties,* in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 249, *Plastics,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 22007-2:2015), which has been technically revised.

The main changes are as follows:

- Figure 2 has been corrected;
- the term "penetration depth" (former 3.1) has been deleted;
- several Notes have been changed to body text;
- reference has been made in the main text to the theory of sensitivity coefficients.

A list of all parts in the ISO 22007 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

A significant increase in the development and application of new and improved materials for broad ranges of physical, chemical, biological, and medical applications has necessitated better performance data from methods of measurement of thermal-transport properties. The introduction of alternative methods that are relatively simple, fast, and of good precision would be of great benefit to the scientific and engineering communities[1].

A number of measurement techniques described as transient methods have been developed of which several have been commercialized. These are being widely used and are suitable for testing many types of materials. In some cases, they can be used to measure several properties separately or simultaneously[2],[3].

A further advantage of some of these methods is that it has become possible to measure the true bulk properties of a material. This feature stems from the possibility of eliminating the influence of the thermal contact resistance (see 8.1.1) that is present at the interface between the probe and the specimen surfaces[1],[3],[4],[5],[6].

Plastics — Determination of thermal conductivity and thermal diffusivity —

Part 2:
Transient plane heat source (hot disc) method

1 Scope

This document specifies a method for the determination of the thermal conductivity and thermal diffusivity, and hence the specific heat capacity per unit volume of plastics. The experimental arrangement can be designed to match different specimen sizes. Measurements can be made in gaseous and vacuum environments at a range of temperatures and pressures.

This method gives guidelines for testing homogeneous and isotropic materials, as well as anisotropic materials with a uniaxial structure. The homogeneity of the material extends throughout the specimen and no thermal barriers (except those next to the probe) are present within a range defined by the probing depth(s) (see 3.1).

The method is suitable for materials having values of thermal conductivity, λ, in the approximate range $0{,}010\ \text{W·m}^{-1}\text{·K}^{-1} < \lambda < 500\ \text{W·m}^{-1}\text{·K}^{-1}$, values of thermal diffusivity, α, in the range $5 \times 10^{-8}\ \text{m}^2\text{·s}^{-1} < \alpha < 10^{-4}\ \text{m}^2\text{·s}^{-1}$, and for temperatures, T, in the approximate range $50\ \text{K} < T < 1\,000\ \text{K}$.

NOTE 1 The specific heat capacity per unit volume, C, $C = \rho \cdot c_p$, where ρ is the density and c_p is the specific heat per unit mass and at constant pressure, can be obtained by dividing the thermal conductivity, λ, by the thermal diffusivity, α, i.e. $C = \lambda/\alpha$, and is in the approximate range $0{,}005\ \text{MJ·m}^{-3}\text{·K}^{-1} < C < 5\ \text{MJ·m}^{-3}\text{·K}^{-1}$. It is also referred to as the volumetric heat capacity.

NOTE 2 If the intention is to determine the thermal resistance or the apparent thermal conductivity in the through-thickness direction of an inhomogeneous product (for instance a fabricated panel) or an inhomogeneous slab of a material, reference is made to ISO 8301, ISO 8302 and ISO 472.

The thermal-transport properties of liquids can also be determined, provided care is taken to minimize thermal convection.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 22007-1, *Plastics — Determination of thermal conductivity and thermal diffusivity — Part 1: General principles*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 22007-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1
probing depth

d_p

measure of how far into the specimen, in the direction of heat flow, a heat wave has travelled during the time window used for calculation

Note 1 to entry: The probing depth is given by:

$$d_p = \kappa \sqrt{\alpha \cdot t_{max}}$$

where

t_{max}	is the maximum time of the time window used for calculating the thermal-transport properties;
α	is the thermal diffusivity of the specimen material;
κ	is a constant dependent on the sensitivity of the temperature recordings.

Note 2 to entry: It is expressed in metres (m).

Note 3 to entry: A typical value in hot disc measurements is $\kappa = 2$, which is assumed throughout this document.

3.2
sensitivity coefficient

β_Ψ

coefficient defined by the formula

$$\beta_\Psi = \Psi \frac{\partial[\Delta T(t)]}{\partial \Psi}$$

where

Ψ	is the thermal conductivity, λ, the thermal diffusivity, α, or the volumetric specific heat capacity, C;
$\Delta T(t)$	is the mean temperature increase of the probe.

Note 1 to entry: Different sensitivity coefficients are defined for thermal conductivity, thermal diffusivity, and specific heat per unit volume[7].

Note 2 to entry: To define the time window that is used to determine both the thermal conductivity and diffusivity from one single experiment, the theory of sensitivity coefficients is used. Through this theory, which deals with a large number of experiments and considers the constants, Ψ, as variables, it has been established that

$$0{,}30 < t_{max} \cdot \alpha / r^2 < 1{,}0$$

where r is the mean radius of the outermost spiral of the probe.

Assuming $\kappa = 2$, this expression can be rewritten as:

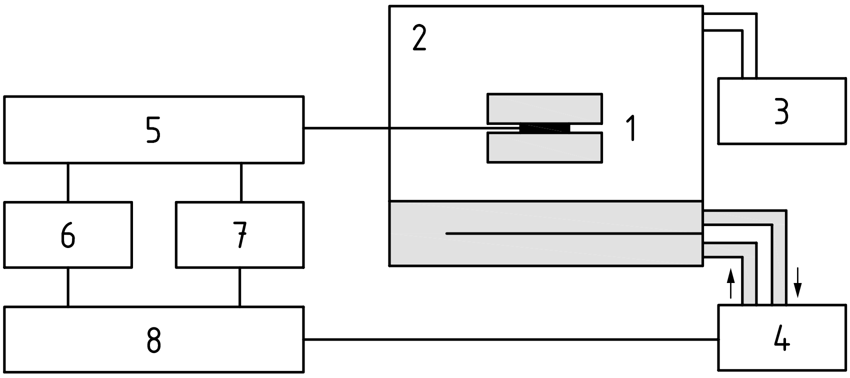
$1{,}1r < d_p < 2{,}0r$.

4 Principle

A specimen containing an embedded hot disc probe of negligible heat capacity shall be equilibrated at a given temperature. A heat pulse in the form of a stepwise function is produced by an electrical current through the probe to generate a dynamic temperature field within the specimen. The increase in the temperature of the probe is measured as a function of time. The probe operates as a temperature sensor unified with a heat source (i.e. a self-heated sensor). The response is then analysed in accordance with the model developed for the specific probe and the assumed boundary conditions.

5 Apparatus

5.1 A schematic diagram of the apparatus is shown in Figure 1.

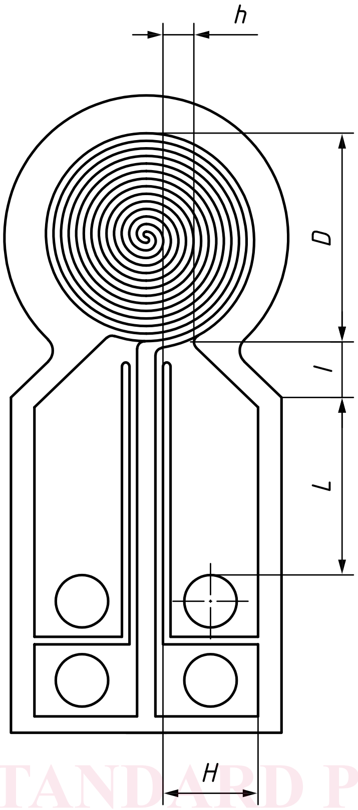


Key

1	specimen with probe
2	chamber
3	vacuum pump
4	thermostat
5	bridge circuit
6	voltmeter
7	voltage source
8	computer

Figure 1 — Basic layout of the apparatus

5.2 A typical hot disc probe is shown in Figure 2. Convenient probes can be designed with diameters from 2 mm to 200 mm, depending on the specimen size and the thermal-transport properties of the material to be tested. The probe is constructed as a bifilar spiral etched out of a (10 ± 2) µm thick metal foil and covered on both sides by thin (from 7 µm to 100 µm) insulating film. Nickel or molybdenum should be used as the heater/temperature-sensing metal foil due to their relatively high temperature coefficient of electrical resistivity and stability over a wide temperature range. Polyimide, mica, aluminium nitride, or aluminium oxide should be used as the insulating film, depending on the ultimate temperature of use. The arms of the bifilar spiral forming an essentially circular probe shall have a width of (0,20 ± 0,03) mm for probes with an overall diameter of 15 mm or less and a width of (0,35 ± 0,05) mm for probes of larger diameter. The distance between the edges of the arms shall be the same as the width of the arms.



Key

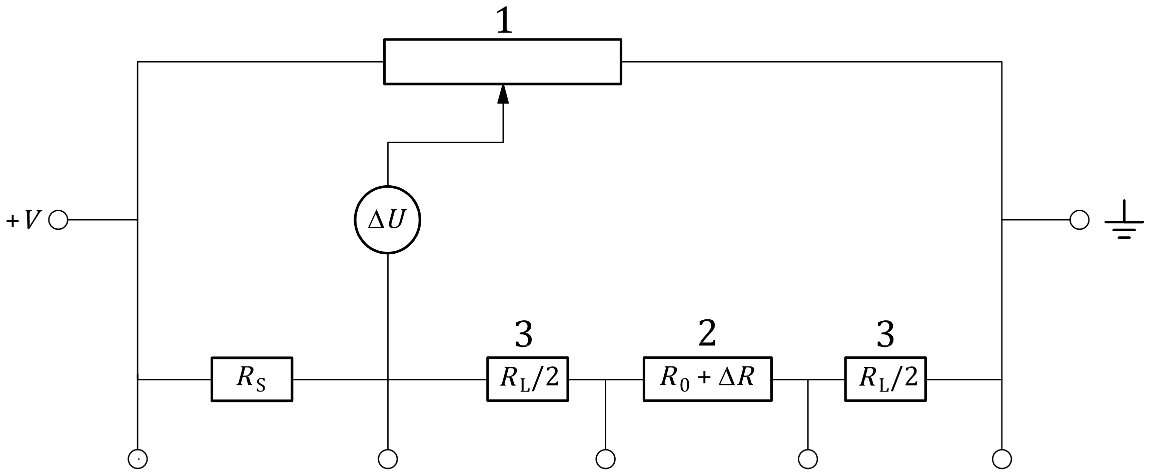
D	sensor diameter
H, h, L, l	dimensions of sensor details

The distances indicated in this figure shall be measured in any but the same unit of length, when used to calculate the heat loss through the electrical leads according to 8.5.2.

Figure 2 — Hot disc probe with bifilar spiral as heating/sensing element

5.3 An electrical bridge shall be used to record the transient increase in resistance of the probe. Through the bridge, which is initially balanced, the increase in resistance of the probe shall be followed by recording the imbalance of the bridge with a sensitive voltmeter (see Figure 3). With this arrangement, the probe is placed in series with a resistor which shall be designed in such a way that its resistance is kept strictly constant throughout the transient. These two components are combined with a precision potentiometer, the resistance of which shall be about 100 times larger than the sum of the resistances of the probe and the series resistor. The bridge shall be connected to a power supply which can supply 20 V and a current of up to 1 A. The digital voltmeter by which the difference voltages are recorded shall have a resolution corresponding to 6,5 digits at an integration time of 1 power line cycle.

The resistance of the series resistor, R_S, shall be close to the initial resistance of the probe with its leads, $R_0 + R_L$, in order to keep the power output of the probe as constant as possible during the measurement.



Key

1 potentiometer
2 probe
3 probe leads

R_L total resistance of the probe leads
R_S series resistance
R_0 initial resistance of the probe before initiating the transient heating
ΔR increase in resistance of the probe during the transient heating
ΔU voltage imbalance created by the increase in the resistance of the probe

NOTE This experimental arrangement allows the determination of temperature deviations from the iterated straight line (see treatment of experimental data in 8.1) down to or better than 50 μK.

Figure 3 — Diagram of electrical bridge for recording the resistance increase of the probe

5.4 A constant-temperature environment controlled to ±0,1 K or better for the duration of a measurement shall be established (see Figure 1). The chamber need only be evacuated when working with slab specimens (see 6.3).

6 Test specimens

6.1 Bulk specimens

6.1.1 For bulk specimens, the requirement for specimen thickness depends on the thermal properties of the material from which the specimen is made. The expression for the probing depth contains the diffusivity, which is not known prior to the measurement. This means that the probing depth shall be calculated after an initial experiment has been completed. If, with this new information, the probing depth is found to be outside the limits given in 8.1.3, the test shall be repeated, with an adjusted total measurement time, until the required conditions are fulfilled.

The shape of the specimen can be cylindrical, square, or rectangular. Machining to a certain shape is not necessary, as long as a flat surface (see 6.1.4) on each of the two specimen halves faces the sensor and the requirements regarding sensor size given in 8.1.3 are fulfilled.

6.1.2 The measurement shall be conducted in such a way that the probing depth into the specimen shall be at least 20 times the characteristic length of the components making up the material or of any inhomogeneity in the material, such as the average diameter of the particles if the specimen is a powder.