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Plastics — Determination of thermal conductivity and thermal diffusivity —

Part 6:

Comparative method for low thermal conductivities using a temperature-modulation technique

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

Partie 6: Méthode comparative pour faibles conductivités thermiques utilisant une technique de modulation de la température

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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ISO 22007-6 was prepared by Technical Committee ISO/TC 61, *Plastics*, Subcommittee SC 5, *Physical-chemical properties*.

ISO 22007 consists of the following parts, under the general title *Plastics — Determination of thermal conductivity and thermal diffusivity*:

- Part 1: *General principles*
- Part 2: *Transient plane heat source method*
- Part 3: *Temperature wave analysis method*
- Part 4: *Laser flash method*
- Part 5: *Determination of thermal conductivity and thermal diffusivity of poly(methyl methacrylate)*(ISO/TR)
- Part 6: *Comparative method for lower thermal conductivity in the modulated temperature field*

Introduction

Thermal insulating properties have become more important in view of power-saving technology. The method which is applicable to measure the lower thermal conductivity in smaller scale with a small amount of a specimen, such as a tray for food, a thermal printing film, a gelled sheet for the electric parts inside laptop PC, an adhesive paste, etc., is required for the micro-scale thermal design of plastics. A double-sensor system of high-sensitivity thermopile located in the different distances in the modulated temperature field, which is controlled by the Peltier thermo-module, is proposed for the determination of thermal conductivity of plastics. A decay parameter is utilized to determine the thermal conductivity of the sample. This method is applied to the measurement of low thermal conductivity in the range below 1,0 W/mK.

In contrast to pulse or transient method, high sensitivity and high-temperature resolution are characteristic of temperature modulated technique, in which employment of a lock-in amplifier reduces any influence of noise and interference.

This international standard specifies a modulated temperature method to determine the thermal conductivity with a small temperature variation, minimizing the influence of the radiation and convection.

Plastics — Determination of thermal conductivity and thermal diffusivity — Part 6: Comparative method for low thermal conductivities using a temperature-modulation technique

1 Scope

The thermal conductivity of materials that are poor conductors of heat is usually determined by measuring the larger temperature gradients in the sample produced by a steady flow of heat in one-dimensional geometry. In order to reduce the errors of radiation and convection, it often requires large, precisely shaped samples and extreme care to be used successfully.

This international standard specifies a modulated temperature method realizing the measurement of thermal conductivity. An input of temperature deviation is less than 1 K, and a double lock-in method is applied to amplify the small temperature modulation.

The ISO22007-3 specifies one of the modulated temperature methods where the phase shift is measured in the thermally thick condition kd >>1 ($k=(\omega/2\alpha)^{1/2}$, ω: angular frequency of temperature wave, α thermal diffusivity, d: thickness of the specimen). In this condition, the backing material does not affect on the phase shift results on the sensor, on which temperature wave decays exponentially.

On the other hand, if kd << 1, the decay of temperature modulation is influenced by the backing materials. Based on this principle, this standard specifies the method to determine the thermal conductivity of the sample (as a backing material), comparing the decay of temperature wave detected on both surfaces of the probe material.

Thermal conductivity is determined from the correlation between the thermal impedance and the decay ratio of amplitude using two reference materials measured at the same frequency and temperature. For instance, if water and air are chosen for reference materials, thermal conductivity is determined in the range from 0,026 W/mK to 0,6 W/mK.

The covering range is adjusted with the reference materials and the probe materials.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. 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 — General Principles*

ISO 22007-3, *Plastics — Determination of thermal conductivity and thermal diffusivity — Temperature wave analysis method*

ISO 31-4, *Quantities and units — Part 4: Heat*

ISO 472, *Plastics —Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 472, ISO 31-4, ISO 22007-1, ISO 22007-3 and the following apply.

3.1

amplitude of temperature modulation

Amp

amplitude of the temperature oscillation produced by a modulated-power heat source

3.2

gain, ratio of *Amp* at *x*=*d* to *x*=0

ζ

amplitude ratio of the front and rear surfaces of the probe material.

$$\zeta = \frac{T_d}{T_0} = \frac{Amp_{x=d}}{Amp_{x=0}} \tag{1}$$

where T_0 and T_d is the amplitude of modulated temperature measured on the sensor 1 (at x=0) and the sensor 2 (x=d), respectively.

3.3

thermal penetration depth

D_p

the periodic oscillations can only be observed for the depths below D_p defined as

$$D_p = 2\pi\sqrt{\frac{2\alpha}{\omega}} \tag{2}$$

where

α is thermal diffusivity;

ω is angular frequency;

D_p the amplitude of the temperature oscillation is attenuated to 0.19% such as

$$\exp(-\sqrt{\frac{\omega}{2\alpha}}D_p) = \exp(-2\pi) \cong 0{,}0019 \tag{3}$$

3.4

thermal diffusion length

1 / k

where

k is defined as

$$k = \sqrt{\frac{\omega}{2\alpha}} \tag{4}$$

4 Principle

As depicted in Fig. 1, the probe material in a flat sheet shape is set between the heat source and the sample, assuming the one – dimensional heat flow.

The heat source generates a temperature modulation at a constant amplitude, keeping the average temperature constant that is realized by using a thermo-electric type (Peltier type) temperature control. Due to the large heat capacity of the heat sink, the temperature modulation in the heat source is not affected by the sample, and the input temperature (*x=0*) on the probe is kept constant.

The sample is attached to the other side of the probe material. In the thermally thin condition, $kd \ll 1$, the decaying temperature modulation at *x=d* is influenced by the sample.

The modulated temperatures at *x=0* and *x=d* are precisely measured by the attached temperature sensor, respectively, using a lock-in amplification.

The characteristic of the principle is listed as below:

1. A small temperature change of the modulated temperature, for instance, less than ±1 K, is given at a room temperature. The average temperature is kept at a room temperature, using a thermo-electric type (Peltier-type) temperature control.
2. The temperature at a bottom of the heat sink (an opposite side from x=0), a deep location in the sample (an opposite side from x=d), and the cold-junction of the thermopile sensor, are considered as the room temperature.
3. A one-dimensional heat flow is attained, measuring a small area located in the centre of the plane heat flow.
4. The frequency for the measurement is chosen considering the thermal diffusion length of a probe material.
5. The lock-in amplification, that is characteristic of the modulation technique, enables to measure the small temperature variation that minimizes the influence of the radiation and convection.

5 Apparatus

5.1 General

The apparatus shall be designed to obtain the amplitude decay ratio of the temperature wave as described in clause 4 and shall consist of the following main components as shown in Figure 1.