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Plastics — Determination of thermal conductivity and thermal diffusivity —

Part 4:
Laser flash method

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

Partie 4: Méthode flash laser

Reference number
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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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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 22007-4 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 (hot disc) method*

— *Part 3: Temperature wave analysis method*

— *Part 4: Laser flash method*

INTERNATIONAL STANDARD **ISO 22007-4:2008(E)**

Plastics — Determination of thermal conductivity and thermal diffusivity —

Part 4:
Laser flash method

1 Scope

1.1 This part of ISO 22007 specifies a method for the determination of the thermal diffusivity of a thin solid disc of plastics in the thickness direction by the laser flash method. This method is based upon the measurement of the temperature rise at the rear face of the thin-disc specimen produced by a short energy pulse on the front face.

1.2 The method can be used for homogeneous solid plastics as well as composites having an isotropic or orthotropic structure. In general, it covers materials having a thermal diffusivity, α, in the range $1 \times 10^{-7}\ \mathrm{m^2 \cdot s^{-1}} < \alpha < 1 \times 10^{-4}\ \mathrm{m^2 \cdot s^{-1}}$. Measurements can be carried out in gaseous and vacuum environments over a temperature range from $-$ 100 °C to $+$ 400 °C.

NOTE For inhomogeneous specimens, the measured values may be specimen thickness dependent.

2 Normative references

The following referenced documents are indispensable for the application 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 291, *Plastics — Standard atmospheres for conditioning and testing*

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

ISO/IEC Guide 98-3, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

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

3.1
pulse width
t_{p}
time duration for which the laser pulse intensity is larger than half of its maximum value

NOTE It is expressed in seconds (s).

3.2
time origin

t_0

start of the laser pulse

NOTE It is expressed in seconds (s).

3.3
maximum temperature rise

ΔT_{max}

difference between the maximum temperature reached by the rear face of the specimen after the laser pulse has passed and its steady temperature before the pulse

NOTE It is expressed in kelvins (K).

3.4
half-rise time

$t_{1/2}$

time from the time origin until the rear-face temperature increases by one-half of ΔT_{max}

NOTE It is expressed in seconds (s).

3.5
thermogram

temperature versus time curve for the rear face of the specimen

3.6
thickness

d

dimension of the test specimen in the direction of heat transfer measurement

NOTE It is expressed in metres (m).

4 Principle

One side of a flat-sheet test specimen is subjected to an energy pulse which has a very short duration compared with the half-rise time (see 6.1) and a uniform spatial energy distribution. The transient temperature rise on the opposite face (rear face) is recorded as a function of time (see Figure 1). The thermal diffusivity is obtained by comparing the experimental thermogram with a theoretical model (see Clause 9 and Annex B).

5 Apparatus

5.1 General

The apparatus shall be designed to obtain the thermal diffusivity as described in Clause 4 and shall consist of the following main components as shown in Figure 2. These are the furnace or climatic chamber with a specimen holder and temperature measurement device (e.g. thermocouple), the flash source (e.g. laser), the pulse detector, the transient detector (IR detector) and the control, data acquisition and analysis unit.

5.2 Furnace or climatic chamber

The furnace or climatic chamber shall meet the following requirements:

a) The temperature range shall be appropriate to the range of materials to be studied. Depending on the range of temperature, the specimen is maintained at a constant temperature by a cryostat or by a furnace.

b) It shall be capable of maintaining the test temperature constant to within ± 0,5 K or less for at least 30 min.

c) The temperature measurement device shall be capable of measuring the furnace temperature with a resolution of ± 0,1 K and an accuracy of ± 0,5 K or better.

d) The furnace shall be fitted with two windows, one transparent to the pulse radiation and the other transparent to the working wavelength range of the IR detector.

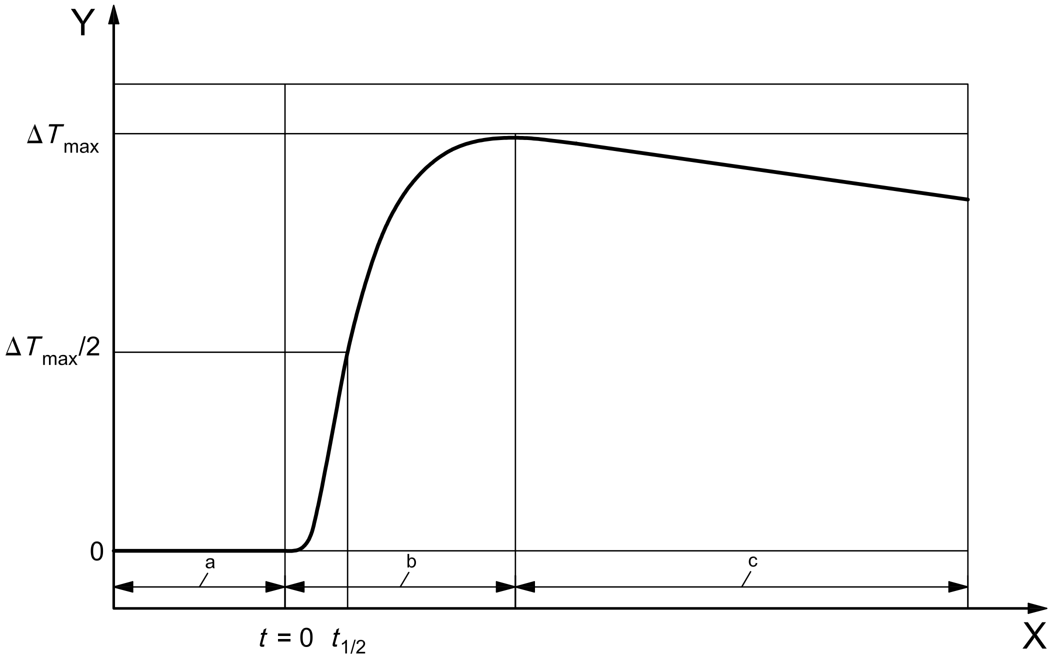
e) If required, the environment in the furnace shall be a vacuum or an inert-gas atmosphere to avoid oxidative degradation during heating and testing of the specimen. For cryoscopic measurements, care shall be taken to avoid water condensation on the windows.

NOTE Measurement under vacuum will eliminate convection effects.

The specimen holder shall be designed to minimize thermal contact with the specimen and to suppress stray light transmitted from the laser beam to the IR detector.

The test temperature shall be measured using a calibrated temperature measurement device that is preferably in contact with the specimen or the specimen holder but at least within 1 mm of the specimen holder.

The temperature measurement device shall be designed so as not to significantly disturb the temperature field generated in the specimen by the laser pulse.



Key

X time

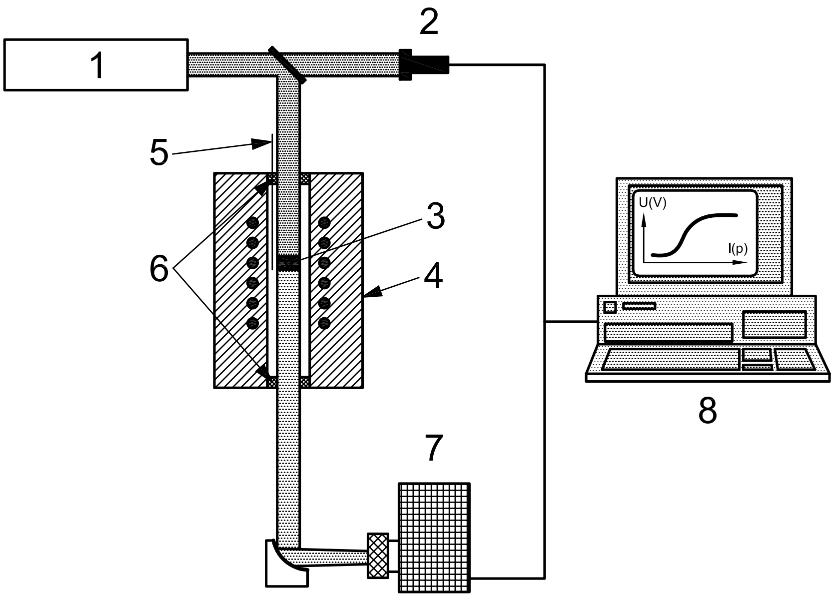
Y temperature rise

[a] Baseline.

[b] Transient-rise period.

[c] Cooling period.

Figure 1 — Example of thermogram



Key

1	flash source
2	pulse detector
3	specimen
4	furnace or climatic chamber
5	temperature measurement device
6	windows
7	transient detector
8	control, acquisition and analysis unit

Figure 2 — Schematic diagram of laser flash set-up for measuring thermal diffusivity

5.3 Flash source

The energy level of the flash source shall produce a temperature rise not exceeding 3 K at the rear face of the specimen.

The spatial energy distribution of the pulse heating shall be as uniform as possible over the front face of the specimen.

The pulse duration shall be shorter than 1 ms.

The heat pulse source may be a laser (preferably) or a flash tube.

A photodiode can be used to determine the duration and form of the pulse and the time origin.

5.4 Transient detectors

The transient temperature rise at the rear face of the specimen shall be measured with an IR detector. The transient detector shall be able to detect a variation of 5 mK in the specimen rear face temperature. Its response shall be linear with temperature over a temperature range of at least 3 K.

The frequency response of the detector and its associated electronics (amplifiers, analogue/digital converters, etc.) shall be faster than 10 kHz. If electronic filters are used, they shall meet the requirements defined above and shall not decrease the accuracy of temperature measurement, otherwise they could distort the shape of the temperature-time curve.

NOTE The choice of IR detector depends also on the temperature range. For the range − 100 °C to + 400 °C, photovoltaic or photoconductor detectors can be used.

The temperature of the rear face, or a quantity directly proportional to it (e.g. voltage), shall be measured and recorded continuously over the duration of the test. The data acquisition system, which may be analogue or digital, shall be able to sample more than 1 000 data points on the thermogram with a sampling frequency higher than $100/t_{1/2}$. The accuracy of the time base shall be better than $\pm 1 \times 10^{-5}$ s.

5.5 Thickness measurement device

The specimen thickness shall be measured with an accuracy of ± 5 µm by a calibrated thickness measurement device having a resolution of ± 1 µm. For soft materials, a micrometer with reproducibly low compression is required.

6 Test specimen

6.1 Shape and dimension of the specimen

The specimen shall be a thin disc. The specimen diameter is usually from 5 mm to 20 mm. The specimen thickness shall be chosen according to the pulse width and the thermal diffusivity of the material. It shall be selected such that the pulse width is less than 0,01 of the half-rise time. Typically, the thickness will be between 0,5 mm and 3 mm. The aspect ratio of the specimen shall be chosen such that 2D effects are negligible during the test. The ratio of the diameter to the thickness shall be larger than 3:1.

The faces shall be flat and parallel. Any variation in the thickness of the specimen should preferably be less than 1 % of the mean thickness. The effect of greater non-uniformity can be estimated in the measurement uncertainty.

6.2 Preparation and conditioning of test specimen

The test specimen shall be representative of the material being examined and shall be prepared and handled with care. If the specimen is taken from sample pieces by cutting, care shall be taken to prevent heating, changes in molecular orientation or any other effect that may alter the sample properties.

The test specimen shall be conditioned prior to the measurement as specified in the relevant material standard or by a method agreed between the parties involved. Unless other conditions are specified, it is recommended that the specimen be conditioned in accordance with ISO 291.

NOTE Depending on the material and its thermal history, the method of test specimen preparation may be crucial to the consistency of the results and their significance.

6.3 Coating the specimen

Specimens which are not opaque to the laser radiation at the wavelength used shall be coated with an appropriate coating (a metal coating, for example) to prevent penetration of the laser beam into the specimen. The influence of the coating on the heat transfer shall be negligible (i.e. it shall have a high diffusivity and low thickness in comparison with the specimen). The total thickness of the coating shall be chosen such that the half-rise time for the coating alone is less than 2 % of the total half-rise time for the specimen.

NOTE 1 The half-rise time, $t_{1/2}$, for the coating can be simply calculated from its thickness, d, and thermal diffusivity, α, using Equation (1), a rearranged form of Equation (B.1):

$$t_{1/2} = 0{,}138\,79\,\frac{d^2}{\alpha} \tag{1}$$

NOTE 2 Both sides of the specimen can be coated with a thin opaque black layer (i.e. a layer of graphite) to optimize the absorption of the energy pulse and the emission of thermal radiation.

7 Calibration and verification

7.1 Calibration of apparatus

The laser flash technique is an absolute method which allows the user to perform measurements that are directly traceable to primary SI units (such as temperature, time, length and voltage) without calibration using reference materials. All elements of the laser flash apparatus shall be calibrated separately, as follows:

- Calibrate the micrometer used to measure the specimen thickness.
- Calibrate the temperature measurement device used to measure the steady-state temperature of the specimen.
- Calibrate the time base and the voltage of the data acquisition system used to measure the signal coming from the IR detector.
- Calibrate the IR detector in order to be able to observe the transient temperature change at the rear face of the specimen rather than the transient spectral irradiance. Perform this calibration mainly for temperatures lower than 200 °C where non-linear behaviour of the output temperature cannot be neglected (see ISO 18755 [1]). If this calibration is not possible (e.g. because the IR detector is inaccessible or due to differences between the optical paths of the IR detector calibration configuration and the thermal-diffusivity measurement configuration), the effects of non-linearity have to be taken into account in the uncertainty of measurement.

7.2 Verification of apparatus

The apparatus should preferably be verified periodically by measuring the thermal diffusivity of one or more reference materials covering the range of thermal diffusivities of the materials to be tested. If the measured values differ by more than 5 % from the reference values, recalibrate the various items of apparatus in accordance with 7.1.

Verification can be carried out by measurements on materials which have well-defined and reproducible thermal properties such as Armco[1)] iron, Poco[1)] graphite, Pyroceram[1)] 9606 or PMMA. Pyroceram 9606 (a ceramic material) has been certified for thermal-diffusivity measurements as part of an international programme involving European metrological laboratories [2]. This certified reference material is available from IRMM (Institute for Reference Materials and Measurements) [3].

It is recommended that the reference materials be chosen so that their properties (half-rise time and thermal diffusivity) are close to those of the materials to be tested.

8 Procedure

8.1 Switch on the equipment at least 1 h prior to any testing to allow it to reach equilibrium.

8.2 Measure the thickness of the specimen at ambient temperature, using a calibrated thickness measurement device. If a specimen coating is used, the specimen-thickness measurement shall be made before coating.

8.3 Mount the specimen in its holder and put this assembly in the furnace.

8.4 If required, establish a vacuum or an inert-gas environment in the furnace.

8.5 Set the furnace temperature to the desired temperature and wait until the stability of the specimen temperature is better than 0,05 K/s.

8.6 Measure the steady-state temperature of the specimen.

[1)] Examples of products available commercially. This information is given for the convenience of users of this part of ISO 22007, and does not constitute an endorsement by ISO of the product named.

8.7 Calculate the specimen thickness at the test temperature, taking into account the change in thickness due to thermal expansion.

8.8 Irradiate the specimen with the laser pulse, taking adequate safety precautions. Care shall be taken to ensure that the laser beam does not cause any local degradation of the specimen. The specimen shall be inspected after removal from the instrument to check for any signs of degradation.

8.9 Measure and record continuously the temperature of the rear face of the specimen or a quantity directly proportional to it before, during and after the laser pulse. The thermogram obtained shall include the baseline, the transient-rise period and the cooling period (see Figure 1).

8.10 If necessary, measure the time form of the laser pulse applied in 8.8 in order to correct for the effect of the finite duration of the pulse (see Annex A).

8.11 From the thermogram obtained, calculate the thermal diffusivity in accordance with Clause 9.

8.12 Repeat at least three times the procedures described from 8.8 to 8.11 at the same temperature and calculate the average value of the thermal diffusivity and the repeatability of the measurements.

The analysis assumes that the specimen is homogeneous. If there are any doubts about the homogeneity, it is recommended that measurements be performed on two specimens with a thickness ratio of about 1:2. If the same diffusivity values are obtained, the effect of inhomogeneity can be assumed to be negligible.

8.13 Change the furnace temperature to the next desired temperature and repeat steps 8.5 to 8.12.

If testing is being carried out at several temperatures, it is recommended that an increasing rather than decreasing temperature profile be used as this will minimize or avoid the effect of distortion of the specimen on the results, as distortion is more likely to occur at higher temperatures.

If testing at elevated temperatures, it is recommended that the effect of possible changes in the specimen at such temperatures be investigated. This can be done by carrying out a test at ambient temperature both before and after the required series of tests. If there is a difference in the results obtained, consideration shall be given to reducing the time at elevated temperature for each specimen.

Care shall be taken to avoid testing at temperatures at which the specimen may undergo a transformation (e.g. first- or second-order transformation, crystal transformation or glass transition) during the test.

NOTE The test temperature is a nominal temperature that can be associated with the measured thermal-diffusivity value as this value is determined under higher transient temperatures due to the heating effect of the laser pulse. An extrapolation procedure [4] can be used to calculate the “intrinsic thermal diffusivity” at the test temperature corresponding to the thermal diffusivity that would be measured for a laser pulse of zero energy.

9 Data analysis

The analysis of the rear-face temperature curve and the calculation of the thermal diffusivity shall be carried out as follows:

a) If the half-rise time, $t_{1/2}$, is shorter than 100 times the pulse width, correct the time scale for the finite pulse time effect in accordance with Annex A.

b) Determine the baseline and the maximum of the curve to calculate the maximum temperature rise, ΔT_{max}. If the baseline shows a drift, correct the thermogram by subtracting the extrapolated baseline.

c) Normalize the rear-face temperature rise curve by dividing all temperature rise values by ΔT_{max}.

d) Calculate the thermal diffusivity from the normalized thermogram, using the partial time moments method [5] described below, or any other suitable method, as well as the thickness, d, corrected for thermal expansion.

The "partial time moments" method recommended in this part of ISO 22007 has a low sensitivity to measurement noise. It uses only the rising part of the thermogram, which is highly sensitive to thermal diffusivity. Other methods may be used as long as their uncertainties are calculated. Annex B gives examples of such methods of calculation.

NOTE 1 Additional information on calculation methods, data analysis and sources of error can be found in ISO 18755 [1]. Since ISO 18755 refers to ceramics, not all the details presented therein are necessarily relevant to the testing of plastics.

In the partial time moments method, the thermal diffusivity is given by Equation (2):

$$\alpha = \frac{d^2 F(m_{-1})}{m_0} \tag{2}$$

The two partial time moments, m_0 and m_{-1}, are defined by Equations (3) and (4):

$$m_0 = \int_{t_{0,1}}^{t_{0,8}} \frac{\Delta T(t)}{\Delta T_{\mathrm{max}}} \mathrm{d}t \tag{3}$$

and

$$m_{-1} = \int_{t_{0,1}}^{t_{0,8}} \frac{1}{t} \times \frac{\Delta T(t)}{\Delta T_{\mathrm{max}}} \mathrm{d}t \tag{4}$$

where

$\Delta T(t)$ is obtained from the experimental thermogram;

$t_{0,1}$ and $t_{0,8}$ are the times required from the initiation of the pulse for the rear face of the specimen to reach 10 % and 80 % of ΔT_{max}.

The function $F(m_{-1})$ is defined by Equations (5) and (6):

For $0{,}44 > m_{-1} > 0{,}27$: $$F(m_{-1}) = 0{,}085\,48 - 0{,}314(0{,}548\,6 - m_{-1}) + 0{,}500(0{,}548\,6 - m_{-1})^{2{,}63} \tag{5}$$

For $m_{-1} > 0{,}44$: $$F(m_{-1}) = -\,0{,}081\,9 + 0{,}305 m_{-1} \tag{6}$$

NOTE 2 Values of m_{-1} less than 0,27 should not be obtained as they do not have any physical significance.

This calculation method can be used if the following conditions are satisfied:

- the duration of the laser pulse is short compared with the time characteristic for thermal diffusion (i.e. pulse width < 1 % of $t_{1/2}$) or, if not, a correction is applied to the time scale in accordance with Annex A;
- the front face of the specimen is uniformly heated by the laser pulse;
- the specimen is homogeneous;
- the specimen is opaque to the laser radiation at the wavelength used.

NOTE 3 The potential effect of non-uniformity of the pulse on the calculated thermal diffusivity can usually be assumed to be negligible due to the use of an IR detector to detect the transient temperature rise of the specimen rear face. However, if needed, the laser beam could be made more uniform by using beam-homogenizing optics.

NOTE 4 The assumption of opacity of the specimen is implicitly satisfied by the deposit of an appropriate coating on its two faces.

10 Uncertainty

The relative expanded uncertainty (confidence level of 95 %) of the thermal-diffusivity determination by the laser flash method with the partial time moments method is estimated to be from ± 3 % to ± 5 % [6] between ambient temperature and 400 °C (depending on the material and the temperature). It has been calculated in accordance with the ISO/IEC Guide 98-3. On the basis of the results of five successive measurements performed under the same conditions, the repeatability of the method is better than 1 %.

11 Test report

The test report shall include the following information:

a) a reference to this part of ISO 22007;

b) the date of the test;

c) all details necessary for complete identification of the sample tested (type, batch number, etc.), including its thermal history;

d) the shape and dimensions (diameter and thicknesses at room temperature and at each test temperature, giving the method of calculation of the thicknesses at the test temperatures) of the specimens and the number of specimens tested;

e) details of sample and specimen preparation;

f) whether a coating was used and, if so, the coating material and coating procedure and the thickness of the coating);

g) the wavelength and duration of the laser pulse;

h) the type of detector used for measuring the transient temperature rise of the specimen rear face;

i) the type of furnace used and its temperature range (or a statement to the effect that a climatic chamber was used);

j) the measurement conditions, such as the test temperature(s), in degrees Celsius, and the furnace atmosphere;

k) the method(s) used to calculate the thermal diffusivity and estimate corrections (e.g. due to heat losses and the finite pulse duration);

l) the thermal-diffusivity value(s) obtained, in square metres per second;

m) any additional information or details of operations not specified in this part of ISO 22007, which may be important for assessment of the results.

Annex A
(informative)

Correction for finite pulse duration

All the methods used to calculate thermal diffusivity assume that the laser pulse is similar to a Dirac function. However, if the duration of the pulse cannot be neglected (see Clause 9), the effect of the finite pulse time should be corrected for.

For the methods of calculation based on the use of the half-rise time, $t_{1/2}$, a first approach consists in calculating the thermal diffusivity, assuming a Dirac function pulse, and applying a correction to the value obtained. By specifying the shapes of pulses, several authors [7],[8],[9] have proposed analytical relationships to estimate this correction.

A more general method consists in shifting the time origin to the centroid, t_g, of the laser pulse and calculating the thermal diffusivity considering the pulse as a Dirac function. In this case, the waveform of the laser pulse is measured by a detector having a response faster than 10 µs and the position of the centroid is calculated directly from the observed waveform. This method, proposed initially by Azumi and Takahashi [10] for adiabatic experiments, has been extended to non-adiabatic ones by Degiovanni [11].

Annex B
(informative)

Alternative methods of calculating thermal diffusivity

All methods of calulating thermal diffusivity are based on the mathematical solution of the heat conduction equation with appropriate initial and boundary conditions. The original method proposed by Parker et al. [12] is based on an analytical model corresponding to an adiabatic experiment, on the basis of which the thermal diffusivity is calculated from the half-rise time, $t_{1/2}$.

In the case of an adiabatic experiment, the thermal diffusivity is calculated simply from the thickness, d, and the half-rise time, $t_{1/2}$, as follows:

$$\alpha = 0{,}13879 \frac{d^2}{t_{1/2}} \tag{B.1}$$

The use of this method, which neglects heat losses, can generate significant systematic errors in thermal-diffusivity determinations. It is not a suitable method for polymers because of their low thermal diffusivity and the test cannot really be considered adiabatic.

Some methods are based on an improvement of Parker's method, introducing correction factors in the calculation of the thermal diffusivity to take into account the unavoidable heat losses. They use one or several characteristic points on the experimental curve. Among them, Cape and Lehman's method [13], Cowan's method [14] and Clark and Taylor's method [15] are the most commonly used.

With the advances in modern data acquisition, methods based on the analysis of a part (i.e. the partial time moments method of Degiovanni and Laurent [5]) or the whole of the temperature response (i.e. the technique proposed by Gembarovic et al. [16] using a least-squares method) are increasingly utilized. These calculation methods are generally based on minimizing the difference between the measured values and the theoretical values obtained from a mathematical model. They differ either by the analytical model used or by the way in which they compare the measured experimental temperature rise versus time recordings with the analytical curve.

Bibliography

[1] ISO 18755, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Determination of thermal diffusivity of monolithic ceramics by laser flash method*

[2] SALMON, D., BAXENDALE, S., GROBOTH, G., HAY, B., HAMMERSCHMIDT, U., BRANDT, R., SINNEMA, S. and BAILLIS, D.: The certification of thermal conductivity and diffusivity properties of Pyroceram 9606 as a reference material up to 1 000 °C, HTCRM, Certification Report (2003)

[3] http://www.irmm.jrc.be

[4] AKOSHIMA, M. and BABA, T.: Thermal Diffusivity Measurements of Candidate Reference Materials by the Laser Flash Method, *Int. J. of Thermophysics*, **26** (1), pp. 151-163 (2005)

[5] DEGIOVANNI, A. and LAURENT, M.: Une nouvelle technique d'identification de la diffusivité thermique par méthode flash, *Rev. Phys. Appl.*, **21**, pp. 229-237 (1986)

[6] HAY, B., FILTZ, J.-R., HAMEURY, J. and RONGIONE, L.: Uncertainty of Thermal Diffusivity Measurements by Laser Flash Method, *Int. J. of Thermophysics*, **26** (6), pp. 1883-1898 (2005)

[7] HECKMAN, R.C.: Finite pulse-time and heat-loss effects in pulse thermal diffusivity measurements, *J. Appl. Phys.*, **44** (4), pp. 1455-1460 (1973)

[8] LARSON, K.B. and KOYAMA, K.: Correction for finite-pulse-time effects in very thin samples using the flash method of measuring thermal diffusivity, *J. Appl. Phys.*, **38** (2), pp. 465-474 (1967)

[9] TAYLOR, R.E. and CLARK, L.M., III: Finite pulse time effects in flash diffusivity method, *High Temp.-High Press.*, **6**, pp. 65-72 (1974)

[10] AZUMI, T. and TAKAHASHI, Y.: Novel finite pulse-width correction in flash thermal diffusivity measurement, *Rev. Sci. Instrum.*, **52** (9), pp. 1411-1413 (1981)

[11] DEGIOVANNI, A.: Correction de longueur d'impulsion pour la mesure de la diffusivité thermique par la méthode flash, *Int. J. Heat Mass Transfer*, **30** (10), pp. 2199-2200 (1987)

[12] PARKER, W.J., JENKINS, R.J., BUTLER, C.P. and ABBOT, G.L.: Flash method of determining thermal diffusivity, heat capacity and thermal conductivity, *J. Appl. Phys.*, **32** (9), pp. 1679-1684 (1961)

[13] CAPE, J.A. and LEHMAN, G.W.: Temperature and finite pulse-time effects in the flash method for measuring thermal diffusivity, *J. Appl. Phys.*, **34** (7), pp. 1909-1913 (1963)

[14] COWAN, R.D.: Pulse method of measuring thermal diffusivity at high temperatures, *J. Appl. Phys.*, **34** (4), pp. 926-927 (1963)

[15] CLARK, L.M., III, and TAYLOR, R.E.: Radiation loss in the flash method for thermal diffusivity, *J. Appl. Phys.*, **46** (2), pp. 714-719 (1975)

[16] GEMBAROVIC, J., VOZAR, L. and MAJERNIK, V.: Using the least square method for data reduction in the flash method, *Int. J. Heat Mass Transfer*, **33** (7), pp. 1563-1565 (1990)

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