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Thermal insulation — Test method for thermal diffusivity — Periodic heat method

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Foreword

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This document was prepared by Technical Committee ISO/TC 163, *[Thermal performance and energy use in the built environment]*, Subcommittee SC 1, *[Test and measurement methods]*.

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.

Thermal insulation — Test method for thermal diffusivity — Periodic heat method

1 Scope

This Standard specifies a periodic heat method for measurement of the thermal diffusivity of thermal insulation material in the shape of a flat plate.

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 8302:1991, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

The list below is always included after each option:

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 http://www.electropedia.org/

3.1
Phase
Quantity that shows the stage of progress in one period of wave motion and other periodic phenomenon. For example, $\omega t+\phi_1$ in $y=A\sin(\omega t+\phi_1)$ is the phase.

3.2
Phase lag
The difference between two phases provided by periodic temperature changes measured at two different points on the surface and inside a test specimen. For example, when the periodic temperature changes 1 and 2 are given by $y_1=A_1\sin(\omega t+\phi_1)$ and $y_2=A_2\sin(\omega t+\phi_2)$, respectively, the phase lag between them is $\phi_2-\phi_1$.

3.3
Amplitude
Amplitude is defined as half of the difference between the maximum and minimum values of the amount of displacement in a periodic temperature change. For example, A in a sine wave given by $A\sin(\omega t+\phi)$ or $A\exp[i(\omega t+\phi)]$ refers to the amplitude.

3.4
Amplitude ratio
The ratio of two amplitudes provided by periodic temperature changes measured at any point on the surface and inside a test specimen. For example, when the periodic temperature changes y_1 on the surface and y_2 inside the test specimen are given by $y_1=A_1\sin(\omega t+\phi_1)$ and $y_2=A_2\sin(\omega t+\phi_2)$, respectively, the amplitude ratio between the two amplitudes is A_2/A_1.

3.5
Period

Period refers to the reproduction interval of a periodic phenomenon (or a periodic function). When the time interval is constant, the period f is given by $f=1/\nu=2\pi/\omega$, where ν is the frequency and ω is the angular frequency.

3.6
Frequency

Frequency is defined as the number of repetitions of the same state within a certain time interval of any temporal periodic phenomena and is expressed as $\nu=1/f$, where f is the period.

3.7
Angular frequency

Angular frequency refers to the rotation angle per second. Angular frequency is obtained by multiplying the frequency ν by 2π ($2\pi\nu$) or by multiplying the reciprocal of the period f by 2π ($2\pi/f$).

3.8
Wavelength

The distance from one point to the next corresponding point of one state which is repeated in a fluctuation.

3.9
Mean temperature of a test specimen

The arithmetic mean temperature between the mean temperature of a high-temperature surface over a single period and the mean temperature of a low-temperature surface over the single same period.

3.10
Temperature difference of a test specimen

The temperature difference between the mean temperature of a high-temperature surface over a single period and the mean temperature of a low-temperature surface over the single same period.

4 Symbols

The symbols used in this standard are given in Table 1.

Table 1 — Symbols

Symbol	Quantity	Unit
a	Thermal diffusivity	m²/s
c	Specific heat capacity	J/(kg·K)
d	Thickness of test specimen (total thickness of the two pieces when using two stacked test pieces in a measurement)	m
f	Period	s
i	Imaginary unit	-
k	Damping coefficient	1/m
L	Length of one side of test specimen	m
l	Distance from periodic heating surface ($d-x_m$)	m
m	Mass prior to measuring thermal diffusivity (prior to grooving)	kg
T	Absolute temperature	K
V	Volume prior to measuring thermal diffusivity (prior to grooving)	m^3
x	x coordinate	m
x_m	Location of temperature measurement point inside a test specimen	m
ε	Phase lag on $x=0$ surface	rad
η	Arbitrary phase	rad

Table 1 *(continued)*

Symbol	Quantity	Unit
θ	Temperature	°C
λ	Thermal conductivity	W/(m·K)
ν	Frequency	1/s
π	Circular constant	-
ρ	Density, bulk density	kg/m^3
φ	Phase lag at $x = x_m$ cross section	rad
ω	Angular frequency	1/s

5 Principle

5.1 General

The periodic heat method is a method for obtaining thermal diffusivity by measuring the temperature at two different points in a test specimen. Thermal diffusivity is evaluated by the phase lag between two phases provided by periodically changing the temperature of one side surface of the test specimen. Here, those temperatures are measured at any point on the heating surface and inside (the internal plane perpendicular to the direction of thermal diffusion) the test specimen.

This measurement method uses a solution of the heat conduction equation that is obtained under the condition that the temperature on one side of a test specimen changes as a trigonometric function of time and the change propagates in a one-dimensional direction, and further, the temperature on the opposite side is kept constant.

The periodical temperature change on the heated surface shall necessarily be expressed by a trigonometric function of time.

It is contrary to the measurement principle to generate a distorted temperature change on the heated surface. In addition, in reality, the waveform easily changes in a distorted temperature change during propagation in a test specimen, and this becomes a cause of measurement errors.

5.2 Calculation of thermal diffusivity and thermal conductivity

As shown in Figure 1, the x-axis is taken upward along the thickness direction of a test specimen, and the heat dissipation surface (the surface in contact with the low-temperature side heater) of the test specimen with thickness d is set as the origin, while the heating surface is set at $x = d$. Accordingly, as shown by the thick arrow, heat flows downward from the heating surface to the heat dissipation surface. At the heat dissipation surface, the temperature is kept constant, and the temperature of the heating surface is changed periodically based on $\theta_H + \theta_0 \sin(\omega t + \eta)$. Under these conditions, the phase lag (rad) between the point at $x = d$ and an arbitrary point at $x = x_m$ is obtained by solving the one-dimensional heat conduction equation. As a result, the following formula (1) is given (see Figure 2).

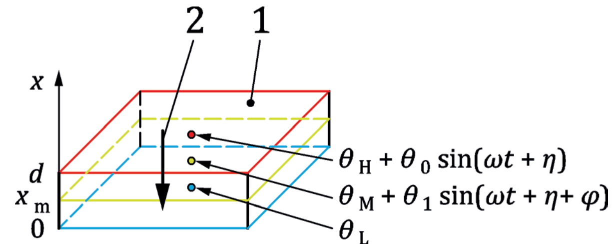

Figure 1 — Relation between test specimen and coordinate (one-dimensional heat flow, in the case θ_L is kept constant)

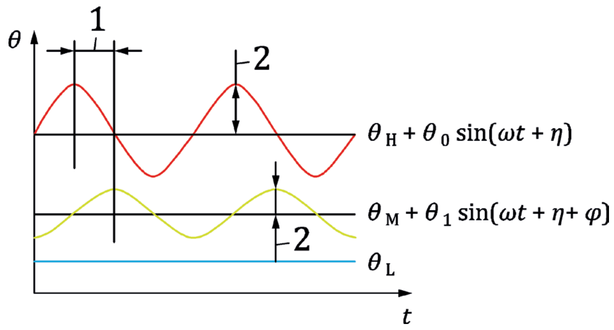

Figure 2 — Periodic temperature change, in the case θ_L is kept constant

$$\phi = \arg\left\{\frac{\sinh kx_m(1+i)}{\sinh kd(1+i)}\right\} \quad (1)$$

The damping coefficient k in formula (1) is defined by formula (2).

$$k = \sqrt{\frac{\omega}{2a}} \quad (2)$$

Also, the angular frequency ω is defined by formula (3).

$$\omega = \frac{2\pi}{f} \quad (3)$$

When using formula (1), the surface temperature on the low-temperature side of a test specimen shall always be controlled so as to be constant.

If the periodical temperature changes on the low-temperature side, as described in Figure 3, it is also possible to solve the phase lag between $x = d$ and $x = x_m$ by solving the one-dimensional heat conduction equation in the same manner as shown above.

As a result, the following formula (4) is given. The coefficients used in formula (4) are shown in formula (5), (6), (7) and (8). The damping coefficient k and the angular frequency ω are defined in formula (2) and (3) in 5.2.

If the temperature on the low-temperature side is constant, formula 4 is equal to formula (1) in 5.2.

$$\varphi = \arctan\left\{\frac{\theta_{1H}\sin(\varphi_H)+\theta_{1L}\sin(\varphi_L+\varepsilon)}{\theta_{1H}\cos(\varphi_H)+\theta_{1L}\cos(\varphi_L+\varepsilon)}\right\} + \begin{cases} 0 \; if \; \theta_{1H}\cos(\varphi_H)+\theta_{1L}\cos(\varphi_L+\varepsilon)\geq 0, \\ \pi \; if \; \theta_{1H}\cos(\varphi_H)+\theta_{1L}\cos(\varphi_L+\varepsilon)< 0, \end{cases} \quad (4)$$

$$\theta_{1H} = \theta_0\sqrt{\frac{\cosh(2kx_m)-\cos(2kx_m)}{\cosh(2kd)-\cos(2kd)}} \quad (5)$$

$$\theta_{1L} = \theta_2\sqrt{\frac{\cosh(2kl)-\cos(2kl)}{\cosh(2kd)-\cos(2kd)}} \quad (6)$$

$$\varphi_H = \arg\left(\frac{\sinh\{kx_m(1+i)\}}{\sinh\{kd(1+i)\}}\right) \quad (7)$$

$$\varphi_L = \arg\left(\frac{\sinh\{kl(1+i)\}}{\sinh\{kd(1+i)\}}\right) \tag{8}$$

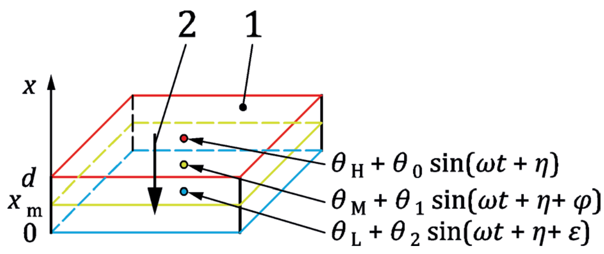

Figure 3 — Relation between test specimen and coordinates (one-dimensional heat flow, in the case θ_L changes periodically)

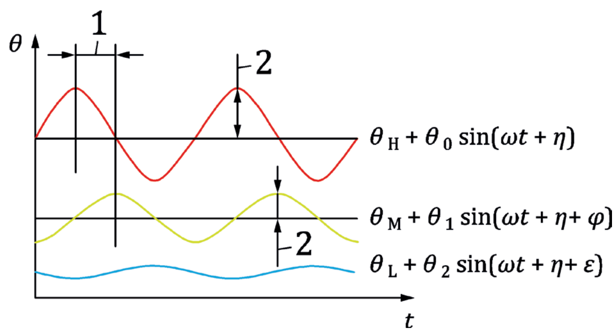

Figure 4 — Periodic temperature change, in the case θ_L changes periodically

6 Test specimen

6.1 Sample

The test specimen taken from the sample shall satisfy the homogeneity prescribed in ISO 8302, 1.8.2. Here, the term "homogeneous" means that raw materials such as fibres and particles constituting the specimen are distributed evenly along the direction of heat flow. Namely, the distribution of fibres and particles is independent of their location in the specimen, and there are no extreme voids inside the specimen. The thermal diffusivity of various kinds of materials like fibrous insulations such as ceramic fibre, rock wool, glass fibre and fibrous board, and furthermore, styrene foam, urethane foam, brick and concrete can be measured by applying the periodic heat method. However, the thermal diffusivity of materials which undergo phase change, release gases, expand or shrink excessively or deform as a result of phenomena such as cracks cannot be measured by this method.

6.2 Details of test specimen

The details of the test specimen are as follows.

a) The dimensions of the test specimen shall be the same as those of the heater for periodic heating with the dimensional tolerance of ±2 mm with respect to the heater dimensions.

b) The relationship between the length L of one side and the thickness d of the test specimen should be restricted so as to reduce the error due to heat inflow (outflow) from the edges of the test specimen. In addition, the minimum thickness d of the test specimen should be restricted so as to reduce the error due to the diameter of the thermocouples on the upper/middle/lower surfaces of the test specimen. For example, when using a 3 mm diameter insulator tube, the minimum thickness d is 20 mm.

c) The heating and low-temperature surfaces of the test specimen shall be smooth, and if necessary, test specimens made of deformable materials shall be held by a support frame or a spacer.

d) The test specimen shall be dried in a drier at 105 °C ± 2 °C until it reaches a constant mass. When there is a risk of alteration or deformation by heat, the test specimen shall be dried until it reaches a constant mass at a temperature that causes no alteration, deformation or other property changes.

e) The bulk density of the test specimen can be calculated by using the following formula (9) based on the volume at the time of measurement of thermal diffusivity and on the mass prior to measurement of thermal diffusivity.