INTERNATIONAL STANDARD

ISO 8894-2

Second edition
2007-12-15

Refractory materials — Determination of thermal conductivity —

Part 2:
Hot-wire method (parallel)

Matériaux réfractaires — Détermination de la conductivité thermique —

Partie 2: Méthode du fil chaud (parallèle)

Reference number
ISO 8894-2:2007(E)

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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 8894-2 was prepared by Technical Committee ISO/TC 33, *Refractories*.

This second edition cancels and replaces the first edition (ISO 8894-2:1990), which has been technically revised to be technically identical to EN 993-15. The main changes are the following. (Note that the clause and subclause references given below refer to the 1990 edition.)

The Scope has been revised. It contains all the essential elements of ISO 8894-2:1990 except that the 1 250°C temperature limit has been omitted. In Note 2, reference to fibres has been taken out as current practice allows measurements on these materials.

Clause 2 *Normative references* has been deleted because

— sampling for this test is not usually carried out in accordance with ISO 5022, and

— ISO 8894-1 is only referred to in the Scope and not in the method itself.

The definitions given in Clause 3 have been improved and clarified.

The accuracy of temperature measurement of the furnace, given in 5.1, has been reduced to ± 10 K.

Modifications to 5.2 to 5.4 reflect equipment currently in use.

A paragraph has been added to 5.7 to ensure that the container is inert under the test conditions.

Subclause 6.4 and Figure 4 have been modified to allow grooves in one test piece only, for simplicity of machining. Bedding material has been removed from Figure 4 as it has been found to affect the results due to heat-transfer modification. A tolerance has been given for surface flatness of the test pieces, so that bedding material is not required.

Subclause 7.2 has been modified to ensure stability of the hot wire and measurement thermocouple.

Table 1 has been modified to reflect modern equipment and 7.5 has been changed accordingly.

A new Clause 7 has been added between 7.11 and Clause 8 to ensure test accuracy.

In the equation In Clause 8, $V.I$ has been replaced by P, the rate of energy transfer, as stated in the definitions in Clause 3.

Annex A has been updated for current practice.

ISO 8894 consists of the following parts, under the general title *Refractory materials — Determination of thermal conductivity:*

— *Part 1: Hot-wire method (cross-array)*

— *Part 2: Hot-wire method (parallel)*

Refractory materials — Determination of thermal conductivity —

Part 2:
Hot-wire method (parallel)

1 Scope

This part of ISO 8894 describes a hot-wire (parallel) method for the determination of the thermal conductivity of refractory products and materials. It is applicable to dense and insulating shaped products and to powdered or granular materials (see 6.2), for thermal conductivities of less than 25 W/m·K. The limits are imposed by the thermal diffusivity of the test material and therefore by the dimensions of the test pieces; higher thermal conductivities can be measured if larger pieces are used. Electrically conducting materials cannot be measured.

NOTE 1 The thermal conductivity of products with a hydraulic or chemical bond can be affected by the appreciable amount of water that is retained after hardening or setting and is released on firing. These materials can therefore require pretreatment. The nature and extent of such pretreatment, and the period for which the test piece is held at the measurement temperature as a preliminary to carrying out the test, are details that are outside the scope of this part of ISO 8894 and are agreed between the parties concerned.

NOTE 2 In general, it is difficult to make measurements on anisotropic materials and the use of this method for such materials is also agreed between the parties concerned.

2 Terms and definitions

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

2.1
thermal conductivity
λ
density of heat flow rate divided by the temperature gradient

NOTE Thermal conductivity is expressed in watts per metre kelvin (W/m·K).

2.2
thermal diffusivity
a
thermal conductivity divided by the bulk density times the specific heat capacity

NOTE 1 $a = \dfrac{\lambda}{\rho \cdot c_\mathrm{p}}$

where

λ is the thermal conductivity;

ρ is the bulk density;

c_p is the specific heat capacity at constant pressure per weight.

NOTE 2 Thermal diffusivity is expressed in square metres per second ($\mathrm{m^2 s^{-1}}$).

2.3
power
P
rate of energy transfer

NOTE Power is expressed in watts (W).

3 Principle

The hot-wire method (parallel) is a dynamic measuring procedure based on the determination of the temperature increase against time at a certain location and at a specified distance from a linear heat source embedded between two test pieces.

The test pieces are heated in a furnace to a specified temperature and maintained at that temperature. Further local heating is provided by a linear electrical conductor (the hot wire) that is embedded in the test piece and carries an electrical current of known power that is constant in time and along the length of the test piece.

A thermocouple is fitted at a specified distance from the hot wire, the thermocouple leads running parallel to the wire (see Figure 1). The increase in temperature as a function of time, measured from the moment the heating current is switched on, is a measure of the thermal conductivity of the material from which the test pieces are made.

4 Apparatus

4.1 Furnace, electrically heated, capable of taking one or more test assemblies (see 5.1) up to a maximum temperature of 1 250 °C. The temperature at any two points in the region occupied by the test pieces shall not differ by more than 10 K. The temperature measured on the outside of the test assembly during a test (of duration about 15 min) shall not vary by more than ± 0,5 K, and shall be known with an accuracy of ± 10 K.

4.2 Hot wire, preferably of platinum or platinum-rhodium, with a minimum length equivalent to that of the test piece. The voltage taps should be located in the test piece with a length between the taps of about 200 mm known to the nearest ± 0,5 mm.

Both ends of the hot wire are attached to the power source and the voltage taps to the digital multimeter (4.5). The wires to the power source may also be a continuation of the hot wire itself and shall have the same diameter as the wire within the assembly. The wires to the digital multimeter shall be of a diameter not greater than that of the hot wire when within the assembly. Leads outside the assembly shall consist of two or more tightly twisted wires of 0,5 mm diameter. The current lead connections external to the furnace shall be made with heavy-gauge cable.

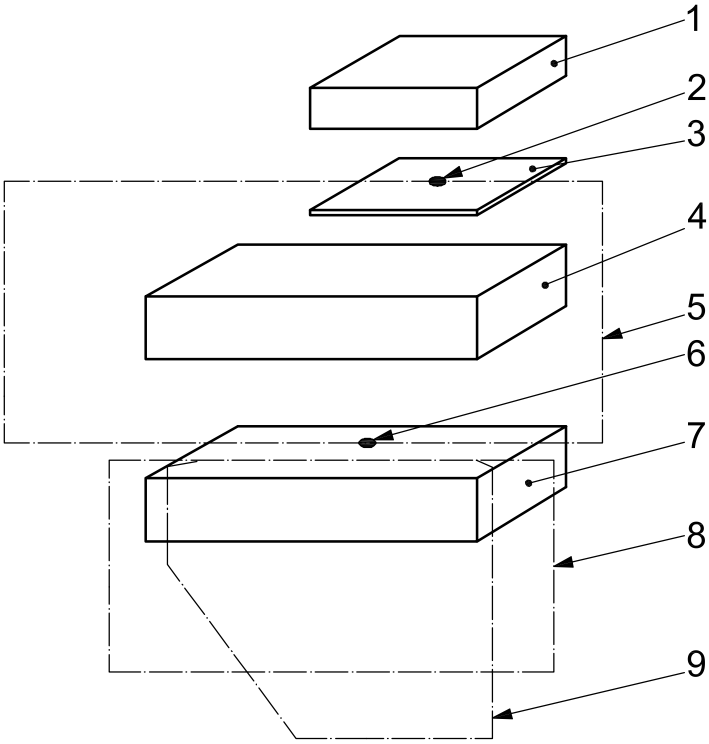
4.3 Power supply, to the hot wire (4.2), which shall be stabilized a.c. or d.c., but preferably a.c., and shall not vary in power by more than 2 % during the period of measurement.

A power supply to the hot wire of at least 250 W/m is required. This is equivalent to 50 W between the voltage taps for a distance of 200 mm.

4.4 Differential platinum/platinum-rhodium thermocouple, (Type R: platinum 13 % rhodium/platinum thermocouple, or Type S: platinum 10 % rhodium/platinum thermocouple, see Table 1) formed from a measurement thermocouple and a reference thermocouple connected in opposition (see Figure 1). The leads of the measurement thermocouple shall run parallel to the hot wire at a distance of 15 mm ± 1 mm (see Figure 2). The output of the reference thermocouple shall be kept stable by placing it between the top outer face of the upper test piece and a cover of the same material as the test piece (see Figure 1). The diameter of the measurement thermocouple wires shall be the same as that of the hot wire and the wires of both thermocouples shall be long enough to extend outside the furnace where connections to the measuring apparatus shall be made by wire of a different type. The external connections of the thermocouple shall be isothermal.

An insulating layer may be inserted between the cover and the upper test piece.

NOTE Base-metal thermocouples can be used at temperatures below 1 000 °C.

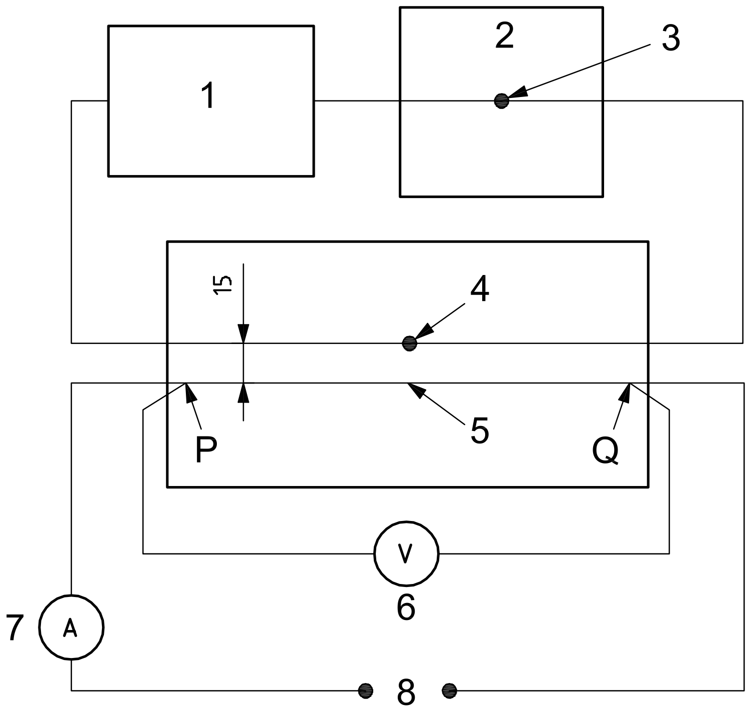


Key

1 Cover
2 Reference thermocouple
3 Optional insulating layer
4 Test piece
5 Measurement circuit
6 Measurement thermocouple
7 Test piece
8 Heating circuit
9 Voltage taps

Figure 1 — Location of heating circuit and measurement circuit (differential thermocouple circuit)

Dimensions in millimetres



Key

1 Temperature/time registration device
2 Cover
3 Reference thermocouple
4 Measurement thermocouple
5 Hot wire
6 Voltmeter
7 Ammeter
8 Power source
PQ = Hot-wire measurement length

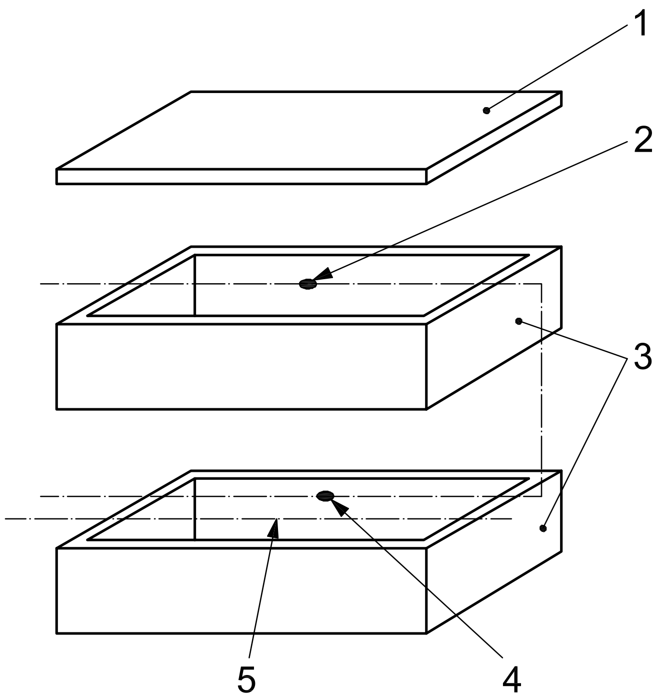
Figure 2 — Measurement arrangement

4.5 Digital multimeter, used for measuring the current in the hot wire and the voltage drop across it, and capable of measuring both to an accuracy of at least ± 0,5 %.

4.6 Data acquisition system, consisting of a temperature-time registration device with a sensitivity of at least 2 μV/cm or 0,05 μV/digit, or a temperature measurement of 0,01 K or better and with a time resolution better than 0,5 s.

4.7 Containers, (for use if the test is performed on powdered or granular material), having internal dimensions equal to those of the solid test assembly specified in Clause 5, so that the test assembly shall consist of two sections as specified in 5.1. The bottom container shall have four sides and a base, and the top container shall have four sides only, plus a detachable cover (see Figure 3).

Containers should be of a material that will not react with the test piece at the test temperature and should not be electrically conducting.



Key

1 Cover
2 Reference thermocouple
3 Containers
4 Measurement thermocouple
5 Hot wire

Figure 3 — Container with hot wire and thermocouple laid on it

5 Test pieces

5.1 Dimensions

Each test assembly shall consist of two identical test pieces, not less than 200 mm × 100 mm × 50 mm in size.

It is recommended that the size of each test piece be 230 mm × 114 mm × 64 mm or 230 mm × 114 mm × 76 mm. Standard-size bricks can then be used as the pieces forming the test assembly, subject to the requirements of 5.2.

The limits of this method are imposed by the dimensions of the test pieces. With larger test pieces, higher values of thermal conductivity can be measured. The distance between the hot wire and the thermocouple should be extended to the same ratio as the test pieces. For example, with a test piece of 230 mm × 180 mm × 95 mm, a thermal conductivity of about 40 W/m·K can be measured.

5.2 Surface flatness

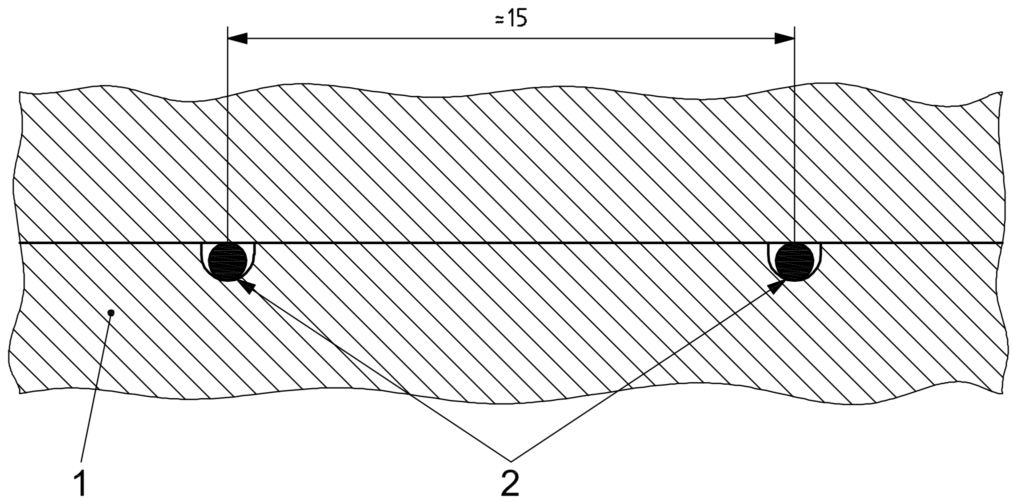
The surfaces of the two test pieces forming the test assembly which are in contact with each other shall, if necessary, be ground so that the deviation from flatness between two points, not less than 100 mm apart, is not more than 0,2 mm.

5.3 Grooves in dense materials

In dense materials, grooves to accommodate the hot wire and the measurement thermocouple shall be machined in the lower face of the test assembly (see Figure 4). The width and depth of the grooves shall permit the arrangement shown in Figure 4 to be achieved.

The faces of the test piece shall be parallel to the nearest ± 1 mm.

Dimensions in millimetres



Key

1 Test piece

2 Grooves with hot wire and thermocouple

Figure 4 — Symmetrical embedding of hot wire and thermocouple in test pieces (where required)

6 Procedure

6.1 Arrange the test assembly ready for testing. Place the hot wire (4.2) and the measurement thermocouple (4.4) between the two test pieces, with the hot wire along the centre-line of the brick faces in contact with each other. Cement them into the grooves where appropriate, using a cement made from finely ground test material mixed with a small amount of a suitable binder (e.g. 2 % dextrin and water). Ensure that the wires are cemented evenly, to allow equal heat transfer to the two test pieces, as shown in Figure 4.

6.2 If the test is being performed on powdered or granular material, fill the bottom container (4.7) with the test material up to its top, and place on it the hot wire and differential thermocouple as shown in Figure 1. Place the top container (4.7) on the bottom one and fill with the test material. Cover the test assembly with a slab of the same material as the containers. Determine the apparent bulk density of the test material in the poured, untamped state. Make sure that the distance between the hot wire and measurement thermocouple is stable during a measurement.

NOTE The container can be filled by vibration or by pressing to give a specific bulk density, where a figure has been agreed upon.

6.3 Place the test assembly in the furnace (4.1), ensuring uniform heating by resting each assembly on three supports of a material similar to that being tested and having dimensions of 125 mm × 10 mm × 20 mm. The supports shall rest on a 125 mm × 10 mm face, and shall be placed parallel to the 114 mm × 76 mm (or 100 mm × 50 mm) faces of the test assembly, about 20 mm from these faces.

6.4 Connect the test assembly to the digital multimeter (4.5). With the hot-wire circuit open, raise the temperature of the furnace, at not more than 10 K/min, to the first test temperature required.

Heating rates should be low enough to ensure that there is no risk of thermal shock damage.

6.5 Set the power input to a value that, from preliminary tests, is known to produce, for a chosen recorder sensitivity, an instrument deflection of at least 60 %, and preferably about 80 %, of full-scale deflection.

A guide to the choice of power input for a range of thermal conductivities and for a range of recorder sensitivities is given in Table 1. The power levels are based on a recorder deflection of 0,8 × full-scale deflection for a given maximum duration of the test (t_{max}).

NOTE The appropriate level of power input to the hot wire will differ between apparatus and needs to be evaluated in preliminary tests, but can eventually be based on experience.

Table 1 — Recommended choice of scales and power level (based on a deflection of 0,8 × full-scale)

Thermal conductivity, λ W/m·K	**Maximum duration of test, t_{max}** s	**Recommended power level** W/m 0 to 50 µV scale
0,1	1 200	3
0,4	1 200	6
1,0	900	15
2,0	450	30
4,0	350	60
8,0	190	120
16	100	240
25	65	375
The figures in this Table 1 are based on the use of type 'S' thermocouples (4.4), and should be adjusted if a type 'R' thermocouple is used.		

6.6 When the furnace reaches the test temperature, verify that the temperature in the region occupied by the test assembly is uniform and constant. The differential thermocouple (4.4) shall not show a variation of more than 0,05 K over a period of 10 min immediately prior to the test.

6.7 When the conditions of 6.6 are met, close the heating circuit and make a record of the output of the differential thermocouple with time. Mark the exact moment when the power input to the hot wire was made. Measure and record the voltage drop across the hot wire between the voltage taps and the current in it, immediately after switching on the heating circuit and again at intervals during the test period.

6.8 After the appropriate test duration (see Table 1), disconnect the heating circuit and discontinue recording the output of the differential thermocouple.

6.9 Allow time for the test assembly to reach temperature equilibrium. Repeat the procedures of 6.7 and 6.8, thus obtaining a further measurement under the same conditions.

6.10 Raise the temperature of the furnace to the next higher test temperature at not more than 10 K/min. Again carry out the procedure described in 6.5 to 6.9.

6.11 Repeat the procedure of 6.10 until at least two measurements have been obtained at each of the required test temperatures.

7 Assessment of results

If the current input to the hot wire has varied by more than 2 % during the test, the results shall be disregarded and the test shall be carried out again.

8 Calculation and expression of results

Calculate the thermal conductivity, λ, of the material, in watts per metre kelvin, at each test temperature using the equation:

$$\lambda = \frac{P}{4\pi l} \times \frac{-Ei\left(\frac{-r^2}{4at}\right)}{\Delta\theta(t)} \quad (1)$$

where

P is the rate of energy transfer, in watts, within the length of the hot wire between the voltage taps, and

$P = V \cdot I$

where

V is the potential difference, in volts;

I is the current, in amperes;

l is the length, in metres, of the hot wire between the voltage taps P and Q in Figure 2;

$\Delta\theta(t)$ is the temperature difference, in kelvins, between the measurement and reference thermocouples at time t;

t is the time, in seconds, from the moment the heating circuit is switched on;

r is the separation, in metres, of the hot wire and the measurement thermocouple;

a is the thermal diffusivity, in square metres per second.

NOTE $-Ei\left(\frac{-r^2}{4at}\right)$ is an exponential integral of the form $\int_x^\infty \frac{e^{-u}\mathrm{d}u}{u}$.

After determining $\frac{\Delta\theta(2t)}{\Delta\theta(t)}$ to 2 decimal places, the expression $-Ei\left(\frac{-r^2}{4at}\right)$ is taken from Table 2, reading the first decimal place from column 1 and the second decimal place from the remaining columns.

The values of λ that can be considered accurate are those that correspond to values of $\frac{\Delta\theta(2t)}{\Delta\theta(t)}$ between 1,5 and 2,4.

Report the result as the mean value of two tests at any one temperature. The individual value of λ as determined in each test should not deviate by more than 5 % from the mean value.

Annex A gives examples of the determination of thermal conductivity.

Table 2 — $-Ei\left(\frac{-r^2}{4at}\right)$ as a function of $\frac{\Delta\theta(2t)}{\Delta\theta(t)}$

$\frac{\Delta\theta(2t)}{\Delta\theta(t)}$	0,00	0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08	0,09
1,1	6,928 7	6,296 6	5,768 9	5,321 3	4,936 6	4,602 1	4,308 5	4,048 3	3,816 2	3,607 7
1,2	3,419 2	3,248 0	3,091 8	2,948 5	2,816 6	2,694 9	2,582 0	2,477 2	2,379 5	2,288 3
1,3	2,202 8	2,122 7	2,047 3	1,976 4	1,909 4	1,846 1	1,786 3	1,729 5	1,675 7	1,624 5
1,4	1,575 8	1,529 5	1,485 2	1,443 1	1,402 8	1,364 2	1,327 4	1,292 0	1,258 2	1,225 7
1,5	1,194 5	1,164 6	1,135 8	1,108 1	1,081 4	1,055 7	1,031 0	1,007 1	0,964 1	0,961 9
1,6	0,940 5	0,919 7	0,889 7	0,880 3	0,861 6	0,843 4	0,825 9	0,808 9	0,792 4	0,776 4
1,7	0,760 9	0,745 9	0,731 3	0,717 1	0,703 4	0,690 0	0,677 0	0,664 4	0,652 1	0,640 2
1,8	0,628 6	0,617 3	0,606 3	0,595 6	0,585 2	0,575 0	0,565,2	0,555 5	0,546 1	0,537 0
1,9	0,528 0	0,519,3	0,510 8	0,502 5	0,494 4	0,486 5	0,478 8	0,471 2	0,463 9	0,456 7
2,0	0,449 6	0,442 8	0,436 0	0,429 5	0,423 0	0,416 8	0,410 6	0,404 6	0,398 7	0,392 9
2,1	0,387 3	0,381 8	0,376 4	0,371 1	0,365 9	0,360 8	0,355 8	0,351 0	0,346 2	0,341 5
2,2	0,336 9	0,332 4	0,328 0	0,323 7	0,319 4	0,316 2	0,311 2	0,307 2	0,303 2	0,299 4
2,3	0,295 6	0,291 9	0,288 2	0,284 6	0,281 1	0,277 6	0,274 2	0,270 9	0,267 6	0,264 4
2,4	0,261 3	0,258 2	0,255 1	0,252 1	0,249 1	0,246 2	0,243 4	0,240 6	0,237 8	0,235 1
2,5	0,232 5	0,229 8	0,227 3	0,224 7	0,222 2	0,219 8	0,217 4	0,215 0	0,212 6	0,210 3
2,6	0,208 1	0,205 8	0,203 6	0,201 5	0,199 3	0,197 2	0,195 2	0,193 1	0,191 1	0,189 2
2,7	0,187 2	0,185 3	0,183 4	0,181 6	0,179 7	0,177 9	0,176 1	0,174 4	0,172 7	0,171 0
2,8	0,169 3	0,167 6	0,166 0	0,164 4	0,162 8	0,161 2	0,159 7	0,158 2	0,156 7	0,155 2
2,9	0,153 7	0,152 3	0,150 9	0,149 5	0,148 1	0,146 7	0,145 4	0,144 1	0,142 7	0,141 4
3,0	0,140 2	0,138 9	0,137 7	0,136 4	0,135 2	0,134 0	0,132 9	0,131 7	0,130 5	0,129 4
3,1	0,128 3	0,127 2	0,126 1	0,125 0	0,123 9	0,122 9	0,121 8	0,120 8	0,119 8	0,118 8
3,2	0,117 8	0,116 8	0,115 8	0,114 9	0,113 9	0,113 0	0,112 1	0,111 2	0,110 3	0,109 4
3,3	0,108 5	0,107 6	0,106 8	0,105 9	0,106 1	0,104 3	0,103 4	0,102 5	0,101 8	0,101 0
3,4	0,100 2	0,099 5	0,098 7	0,097 9	0,097 2	0,096 4	0,095 7	0,095 0	0,094 3	0,093 6
3,5	0,092 8	0,092 2	0,091 5	0,090 8	0,090 1	0,089 5	0,088 8	0,088 1	0,087 5	0,086 9
3,6	0,086 2	0,085 6	0,085 0	0,084 4	0,083 8	0,083 2	0,082 5	0,082 0	0,081 4	0,080 8
3,7	0,080 3	0,079 7	0,079 1	0,078 6	0,078 0	0,077 5	0,077 0	0,076 4	0,075 9	0,075 4
3,8	0,074 9	0,074 4	0,073 9	0,073 4	0,072 9	0,072 4	0,071 9	0,071 4	0,070 9	0,070 5
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4,2	0,057 9	0,057 5	0,057 2	0,056 8	0,056 5	0,056 1	0,055 8	0,055 5	0,055 1	0,054 8
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4,6	0,045 9	0,045 6	0,045 4	0,045 2	0,044 9	0,044 7	0,044 4	0,044 2	0,043 9	0,043 7
4,7	0,043 5	0,043 2	0,043 0	0,042 8	0,042 5	0,042 3	0,042 1	0,041 9	0,041 7	0,041 4
4,8	0,041 2	0,041 0	0,040 8	0,040 6	0,040 4	0,040 2	0,040 0	0,039 8	0,039 6	0,039 3
4,9	0,039 1	0,038 9	0,038 7	0,038 6	0,038 4	0,038 2	0,038 0	0,037 8	0,037 6	0,037 4
5,0	0,037 2	0,037 0	0,036 8	0,036 7	0,036 5	0,036 3	0,036 1	0,035 9	0,035 8	0,035 6
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5,7	0,026 9	0,026 8	0,026 6	0,026 5	0,026 4	0,026 3	0,026 2	0,026 1	0,026 0	0,025 8
5,8	0,025 7	0,025 6	0,025 5	0,025 4	0,025 3	0,025 2	0,025 1	0,025 0	0,024 9	0,024 8
5,9	0,024 7	0,024 6	0,024 5	0,024 4	0,024 3	0,024 2	0,024 1	0,024 0	0,023 9	0,023 8
6,0	0,023 7									

NOTE 1 This table has been made up from statements in the literature (see [1], [2] and [3] in the Bibliography).

NOTE 2 The expressions $\frac{\Delta\theta(2t)}{\Delta\theta(t)}$ and $-Ei\left(\frac{-r^2}{4at}\right)$ are quoted in the literature as $\frac{-Ei(-x/2)}{-Ei(-x)}$ and $-Ei(-x)$, respectively.

9 Precision

No precision data are currently available. While it is possible to evaluate the error caused by the apparatus, the most serious error is caused by the sample preparation. This is not a statistical error which can be quantified.

10 Test report

The test report shall include the following information:

a) all information necessary for identification of the material tested (including manufacturer, product, type, batch number);

b) a reference to this international standard, i.e. ISO 8894-2:2007;

c) details of the procedure, including:

   — any pretreatment given to the test material (see Note 1 to Clause 1);

   — in the case of powders or granular materials, the apparent bulk density in the poured, untamped state (see 6.2);

   — the furnace atmosphere;

   — the test temperature or temperatures and, for each of them, the individual and mean values of thermal conductivity;

d) the results of the test, calculated in accordance with Clause 8;

e) the name of the test laboratory;

f) any deviations from the procedure specified;

g) any unusual features (anomalies) observed during the test;

h) the date of the test.

Annex A
(informative)

Example of the determination of thermal conductivity

Test material: high-alumina brick.

Bulk density: 3,13 g/cm^3.

Test temperature: 500 °C.

Hot wire power: 128 W/m (P/l); Thermocouple: Type "S".

Thermocouple electromotive force (emf) at 500 °C: 9.9 µV/K.

In columns 2 and 3 of Table A.1, the temperature increase at the various times t is given in kelvins (K).

It is essential that the correct thermo-electromotive force is used in the conversion of the measured microvolts to temperature.

NOTE Thermo-electromotive force values for a range of thermocouple types are available (see [4] in the Bibliography).

In column 5 of Table A.1, the expression $\frac{\Delta\theta(2t)}{\Delta\theta(t)}$ is given.

This expression is calculated by dividing the temperature difference after a period 2t by the temperature difference after a period t.

This expression can be calculated from the data measured (see columns 3 and 4 of Table A.1).

EXAMPLES

$$\frac{\Delta\theta(2t)}{\Delta\theta(t)} = \frac{\Delta\theta(120)}{\Delta\theta(60)} = \frac{1{,}683\ \text{K}}{0{,}874\ \text{K}} = 1{,}926$$

$$\frac{\Delta\theta(2t)}{\Delta\theta(t)} = \frac{\Delta\theta(240)}{\Delta\theta(120)} = \frac{2{,}665\ \text{K}}{1{,}683\ \text{K}} = 1{,}583$$

The $-Ei\left(\frac{-r^2}{4at}\right)$ values associated with the individual $\frac{\Delta\theta(2t)}{\Delta\theta(t)}$ values are taken from Table 2, interpolated where necessary, and entered in column 6 of Table A.1.

By substituting the expressions $-Ei\left(\frac{-r^2}{4at}\right)$, $\Delta\theta(t)$, power input and length of the hot wire in the equation in Clause 8, λ is calculated and entered in column 7 of Table A.1.

The time from which λ becomes almost constant depends on the material.

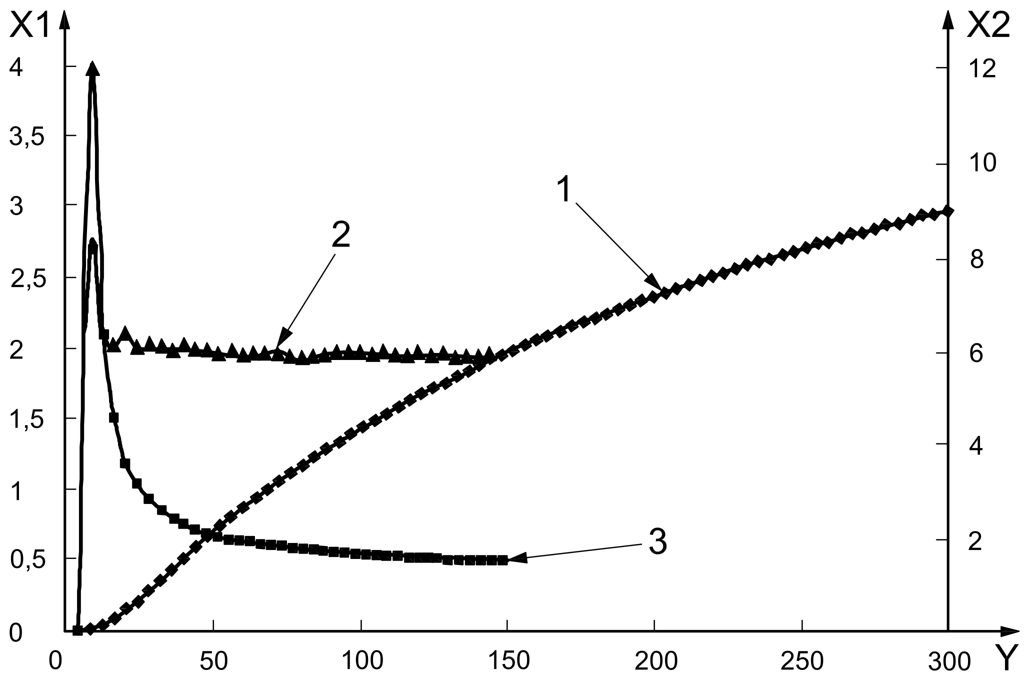
The actual value for λ for the test is the mean value of the accurate values in column 8 of Table A.1.

Table A.1 — Example of an evaluation of the measurements for the determination of the thermal conductivity by the parallel hot-wire method

Time, t s	Time, $2t$ s	$\Delta\theta(t)$ K	$\Delta\theta(2t)$ K	$\frac{\Delta\theta(2t)}{\Delta\theta(t)}$ (Ratio)	$-Ei\left(\frac{-r^2}{4at}\right)$	Thermal conductivity, λ W/m·K	λ mean W/m·K
4	8	0,000	0,010	0,000	0,000	0,000 [a]	
8	16	0,010	0,081	8,100	0,111 43	11,912 [a]	
12	24	0,034	0,214	6,294	0,210 25	6,410 [a]	
16	32	0,081	0,365	4,506	0,048 36	6,051 [a]	
20	40	0,147	0,519	3,531	0,090 72	6,336 [a]	
24	48	0,214	0,666	3,112	0,126 95	6,052 [a]	
28	56	0,291	0,805	2,766	0,175 09	6,121 [a]	
32	64	0,365	0,936	2,564	0,216 39	6,051 [a]	
36	72	0,442	1,065	2,410	0,258 15	5,956 [a]	
40	80	0,519	1,176	2,266	0,308 74	6,058	
44	88	0,593	1,289	2,174	0,349 03	6,010	
48	96	0,666	1,394	2,093	0,391 23	5,989	
52	104	0,734	1,495	2,037	0,424 95	5,917	
56	112	0,805	1,590	1,975	0,467 52	5,928	
60	120	0,874	1,683	1,926	0,505 79	5,908	
64	128	0,936	1,767	1,888	0,538 76	5,875	
68	136	1,003	1,852	1,846	0,579 07	5,883	
72	144	1,065	1,927	1,809	0,618 42	5,928	
76	152	1,124	2,001	1,780	0,652 14	5,912	
80	160	1,176	2,072	1,762	0,674 47	5,857	
84	168	1,237	2,141	1,731	0,715 72	5,909	
88	176	1,289	2,201	1,708	0,748 84	5,936	
92	184	1,342	2,266	1,689	0,777 98	5,922	
96	192	1,394	2,328	1,670	0,808 87	5,921	5,92
100	200	1,447	2,391	1,652	0,839 89	5,917	
104	208	1,495	2,449	1,638	0,865 28	5,903	
108	216	1,546	2,506	1,621	0,897 73	5,924	
112	224	1,590	2,560	1,610	0,919 73	5,899	
116	232	1,638	2,615	1,596	0,948 95	5,911	
120	240	1,683	2,665	1,583	0,977 38	5,916	
124	248	1,723	2,714	1,575	0,995 53	5,898	
128	256	1,767	2,762	1,563	1,023 75	5,915	
132	264	1,808	2,813	1,556	1,040 78	5,879	
136	272	1,852	2,859	1,544	1,071 03	5,908	
140	280	1,889	2,901	1,536	1,091 96	5,897	
144	288	1,927	2,942	1,527	1,116 27	5,918	
148	296	1,963	2,980	1,518	1,141 44	5,935	
150	300	1,979	3,002	1,517	1,144 30	5,904	

[a] Values of $\frac{\Delta\theta(2t)}{\Delta\theta(t)}$ not between 1,5 and 2,4.

The data given in columns 3, 5 and 7 of Table A.1 are plotted in Figure A.1.



Key

X_1 Temperature increase $\Delta\theta(t)$, K

X_2 Thermal conductivity, $\frac{W}{m \cdot K}$ and ratio

Y Measuring time, s

1 $\Delta\theta(t)$

2 Thermal conductivity

3 Ratio

Figure A.1 — Example for a thermal conductivity measurement using the hot-wire (parallel) method at 500 °C (test material: high-alumina brick)

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[4] *Monograph 125 (Thermo-electromotive force values for a range of thermocouple types)*, US National Bureau of Standards

[5] EN 993-15, *Methods of test for dense shaped refractory products — Determination of thermal conductivity by the hot-wire (parallel) method*

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