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Road vehicles — Brake linings — Determination of thermal conductivity by guarded hot-plate apparatus

Véhicules routiers — Garnitures de freins — Détermination de la conductivité thermique par la méthode de la plaque chaude gardée

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ISO/TR 7882 was prepared by Technical Committee ISO/TC 22, *Road vehicles*.

The reasons which led to the decision to publish this document in the form of a technical report type 2 are explained in the Introduction.

0 Introduction

This Technical Report is based on existing data on the method of determination of the thermal conductivity of materials for building and construction.

No experience has yet been acquired by industry on the application of the method to those materials constituting brake linings especially taking into account the extremely high service temperatures. For this reason the document is published as a technical report, type 2.

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1 Scope

This Technical Report describes a method of determining the thermal conductivity of homogeneous materials or the thermal resistance of coated materials by means of the guarded hot-plate apparatus by applying it to brake linings for road vehicles.

The hot-plate apparatus is suitable for materials in the form of flat sheets. The measuring method used is suitable not only for homogeneous materials but also for more or less homogeneous porous, fibrous, granulated or coated materials.

2 Field of application

The method given in this Technical Report applies to materials with a thermal conductivity below 2 kcal/(m·h·°C) [2,3 W/(m·K)].

3 Definitions

For the purposes of this Technical Report, the following definitions apply.

3.1 thermal conductivity, λ: Property of a material which determines the magnitude of the heat flux which, in a given temperature field, flows through the test area under the action of the temperature gradient assumed to be effective in a direction perpendicular to the area concerned.

3.2 thermal resistance, R: Thermal resistance of a material coat of thickness d, equal to d/λ.

4 Units

Thermal conductivity, λ, is expressed in kilocalories per metre hour degree Celsius [kcal/m·h·°C)] or in watts per metre kelvin [W/(m·K)].

Thermal resistance, R, is expressed in square metres hours degree Celsius per kilocalorie (m^2·h·°C/kcal) or in square metres kelvins per watt (m^2·K/W).

Tables 1 and 2 provide conversions into other units in each case.

Table 1 — Conversion of units for thermal conductivity

Conversion \ Unit	kcal/(m·h·°C)	cal/(cm·s·°C)	W/(cm·K)	W/(m·K)
1 kcal/(m·h·°C)	1	0,002 778	0,011 63	1,163
1 cal/(cm·s·°C)	360	1	4,186 8	418,68
1 W/(cm·K)	85,98	0,238 8	1	100
1 W/(m·K)	0,859 8	0,002 388	0,01	1

Table 2 — Conversion of units for thermal resistance

Conversion \ Unit	m^2·h·°C/kcal	m^2·K/W
1 m^2·h·°C/kcal	1	0,859 8
1 m^2·K/W	1,163	1

5 Method of determination

5.1 Principle

Determination of the thermal conductivity of specimens of sheet form from the heat flux and measuring the temperature difference in the steady-state condition, and the specimen dimensions.

5.2 Determination

5.2.1 Two-plate method

In the method using the two-plate apparatus (see figure 1), the mean thermal conductivity is found from two specimens of sheet form which are arranged symmetrically on either side of a hot-plate. From the opposite outer surfaces of the specimens, the heat is conducted away by cooling plates. To prevent heat losses to the side, the hot-plate is surrounded by a hot ring the inside surface temperature of which shall be the same as the temperature of the hot-plate.

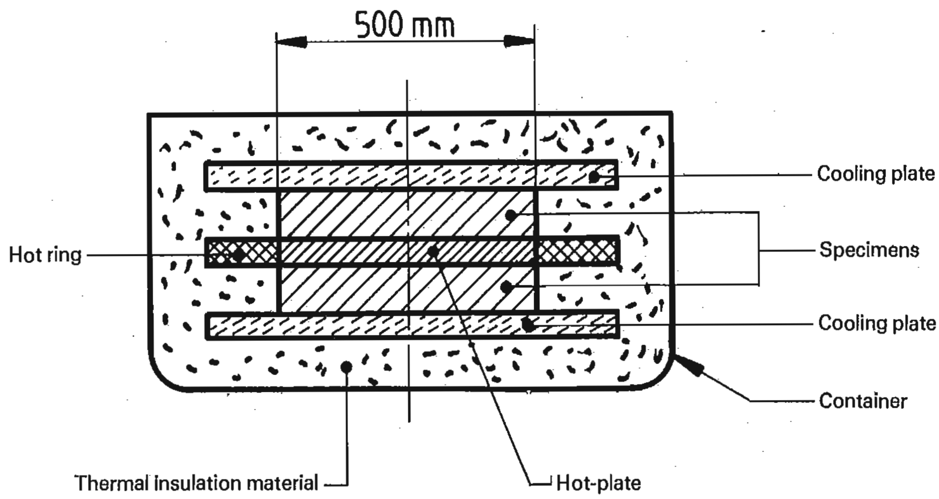

Figure 1 — 500 mm apparatus for the two-plate method (standard apparatus)

5.2.2 Single-plate method

As an alternative to the test using the two-plate method, another method using a single specimen of sheet form for determination of thermal conductivity is also permissible. In this case the outer side of the hot-plate is shielded by another hot-plate (see figure 2).

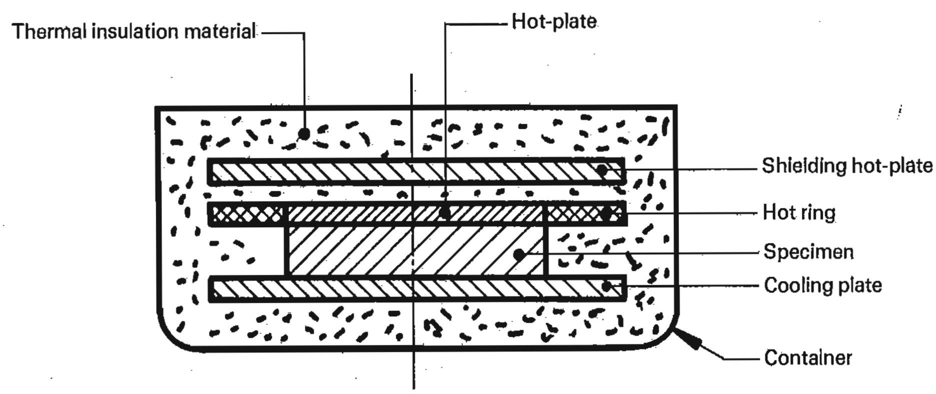

Figure 2 — Test arrangement for the single-plate method

6 Test apparatus

6.1 Hot-plate apparatus (standard apparatus — see figure 1), using a square hot-plate of 500 mm side length. Provided that the materials to be tested are sufficiently homogeneous, the tests can be made with smaller hot-plates including circular shapes. The length of side or diameter of such plates shall not be smaller than 120 mm.

The width of the hot ring shall be not less than 0,25 × the side length of the hot-plate (i.e. 125 mm for the standard apparatus).

For the standard apparatus the gap between the hot-plate and the hot-ring shall normally not be larger than 5 mm, or 2 mm in the case of apparatus with hot-plates of the smaller type (see 11.1.2).

The cooling plates or the shielding hot-plate shall cover the hot-plate and hot ring. The material used for the hot-plate shall be hot, and cooling plates shall be so treated that they have an emission index of not less than 0,8.

The hot-plate and normally the hot ring also shall be electrically heated.

6.2 Temperature measuring devices, to determine

a) the surface temperatures of the specimens on both sides in each case;

b) the temperature difference between the hot-plate and the hot ring;

c) additionally, in the case of the single-plate method, the temperature difference between the hot-plate (outer side) and the shielding hot-plate.

Suitable devices for this purpose are thermocouples and resistance thermometers; the number of such devices and hence the proportion of surface area to be covered by them depends on the size and homogeneity of the specimens.

7 Sampling

The sampling system can be settled by agreement with the applicant, provided that there are no existing agreements or specifications (e.g. standards, implementation orders, quality specifications or other regulations) to be observed.

8 Specimen dimensions and preteatment

8.1 The side length of the specimens shall be at least equal to the side length of the hot-plate.

The dimensions of table 3 are recommended.

Table 3 — Specimen dimensions

Dimensions in millimetres

Side length (or diameter) of hot plate	Specimen thickness	
	max.	min.
200	20	5
120	10	5

8.2 For the two-plate method, the thickness and bulk density of the individual specimens shall not differ by more than 5 % from the arithmetic mean of the thicknesses and bulk densities of the two specimens.

8.3 The surfaces of solid specimens of sheet form shall be flat and parallel. The same principle also applies to specimens with profiled surfaces.

8.4 Prior to testing, the specimens shall be dried at 105 °C and atmospheric pressure, until the mass remains constant.

Mass constancy for the purposes of this Technical Report exists when the change in mass at a drying temperature of 105 °C over a period of 6 h does not exceed 2 ‰, or 1 ‰ over 36 h at 40 °C after adequate predrying over a drying agent (e.g. silica gel) or, where permissible, by the use of vacuum.

In the determination of the dry mass of thermal insulating materials of vegetable origin, appreciable errors may arise if the specimens are able to absorb moisture from the air prior to being weighed. If it is not practicable to take the specimens straight to the scales from the drying oven, it will be necessary to cool them in the desiccator.

It shall be ensured that during the test the specimens absorb the minimum of moisture from the air. This may be achieved, for example, by wrapping with film or foil which is impervious to water vapour. After the test the specimens must be weighed to determine whether the moisture content exceeds the maximum allowable. If so, the test shall be repeated after further drying.

In exceptional cases, and if so agreed, the test can also be carried out on air-dry specimens subject to the limits specified.

Table 4 — Permissible moisture content when testing

Material	Permissible moisture content %	
	min.	max.
Glass fibre, mineral fibre, blast furnace slag fibre Other fibres, including cement-bound types	0	3

8.5 After drying but before the test, the specimens shall be measured, with a sufficient number of measurements being taken to allow an arithmetic mean to be calculated.

9 Mounting the specimen sheets in the apparatus

9.1 It is essential that there should be no air-spaces between the specimens and the hot-plates and cooling plates, except when such spaces are inevitable as a result of the surface profile. When the materials are such that they do not bear completely on the surface of the hot-plates and cooling plates, the resulting air-spaces may be avoided by the use of suitable material.

9.2 Any disturbance of the temperature conditions in the apparatus through environmental effects shall be prevented, for example by the use of thermal insulating materials. This applies in particular to the space between the hot ring and the cooling plates (guard ring). When the materials are of low thermal conductivity, it is recommended that the guard ring also should be made from the specimen material; i.e. in such cases the specimens should be cut such that they completely cover the hot-plate and hot ring.

9.3 With multi-coat specimens, it is essential in all cases that the space between the hot ring and the cooling plates should be filled with the same material as the specimens and in the same lamination. Metallic layers for example covering layers, shall be broken between the hot-plate and the hot ring.

9.4 Care shall be taken to ensure that the temperatures measured are those of the specimen surfaces and not of the hot-plates or cooling plates or of the packing material. The temperature sensor shall therefore bear directly on the specimen surface but without impairing effective contact between the specimen and the hot-plate or cooling plate. This can be achieved by using thin temperature sensors[1].

10 Test conditions

10.1 The value chosen for the temperature difference between the surfaces of the specimens shall preferably not be less than about 10 °C.

10.2 The test shall be carried out at not less than three mean temperatures which shall differ by at least 50 °C. As far as possible the mean temperatures shall lie in the temperature range to which the material will be exposed in service.

11 Calculation and expression of results

11.1 Thermal conductivity

11.1.1 The thermal conductivity, λ, is calculated, according to the method used either from equation (1) or (2):

$$\lambda = \frac{\Phi \times d_m}{2A\,(t_{wm} - t_{km})} \text{ (two-plate method)} \qquad \ldots (1)$$

$$\lambda = \frac{\Phi \times d}{A\,(t_w - t_k)} \text{ (single-plate method)} \qquad \ldots (2)$$

where

Φ is the heat flux passing through the specimen under steady-state conditions in a direction perpendicular to the specimen surface, in kilocalories per hour;

d is the mean thickness of a specimen, in metres;

d_1 and d_2 are the mean thicknesses of specimens 1 and 2 respectively, in metres;

$$d_m = \frac{1}{2}(d_1 + d_2)$$

1) It is recommended that when thermocouples, for example, are used, the maximum thickness of the wires should be 0,2 mm.

A is the surface area of the hot-plate, in square metres;

t_{w1} and t_{w2} are the mean surface temperatures of specimens 1 and 2 respectively, on the hot-plate side, in degrees Celsius;

t_{k1} and t_{k2} are the mean surface temperatures of the specimens 1 and 2 respectively, on the cooling plate side, in degrees Celsius;

$$t_{wm} = \frac{1}{2}(t_{w1} + t_{w2})$$

$$t_{km} = \frac{1}{2}(t_{k1} + t_{k2})$$

Equation (1) for the two-plate method only applies subject to the condition that

$$\frac{(t_w - t_k)_1 - (t_w - t_k)_2}{t_{wm} - t_{km}} < 0{,}2$$

and that 9.3 has also been observed.

With electric heating by direct current, the heat flux is given by the equation

$$\Phi = 0{,}86 \times U \times I \qquad \text{... (3)}$$

where

Φ is in kilocalories (1 kcal = 1,163 W);

U is the voltage, in volts, at the terminals of the hot-plate;

I is the current, in amperes.

The calculated thermal conductivity shall be referred each time to the mean temperature, t_m, between the hot and cold surfaces, according to the equation

$$t_m = \frac{1}{2}(t_{wm} + t_{km}) \quad \text{or} \quad \frac{1}{2}(t_w + t_k) \qquad \text{... (4)}$$

11.1.2 It may be necessary to take into account the heat flux in the gap between the hot-plate and the hot ring as well as in the area below them (single-plate apparatus) and above them (in the case of the two-plate apparatus) and bounded by the specimen and the guard ring. This corresponds to a heat loss by the hot-plate; it can be calculated with the aid of a factor C so that equations (1) and (2) become the corresponding equations (5) and (6):

$$\lambda = \frac{\Phi \times d_m}{2A(t_{wm} - t_{km})} \times \frac{1}{C} \qquad \text{... (5)}$$

$$\lambda = \frac{\Phi \times d}{A(t_w - t_k} \times \frac{1}{C} \qquad \text{... (6)}$$

where factor C is given by the equation

$$C = 1 + \frac{1}{2} \times \frac{A_{sp}}{A} \times \frac{\lambda_{sp}}{\lambda} \qquad \text{... (7)}$$

in which

A_{sp} is the surface area of the gap (see figure 3);

λ_{sp} is the thermal conductivity of the material filling the gap or the region between specimen and guard ring, or air in the case of narrow gaps, or the material under test itself (see 9.4 for specimens which completely cover the hot-plate and hot ring).

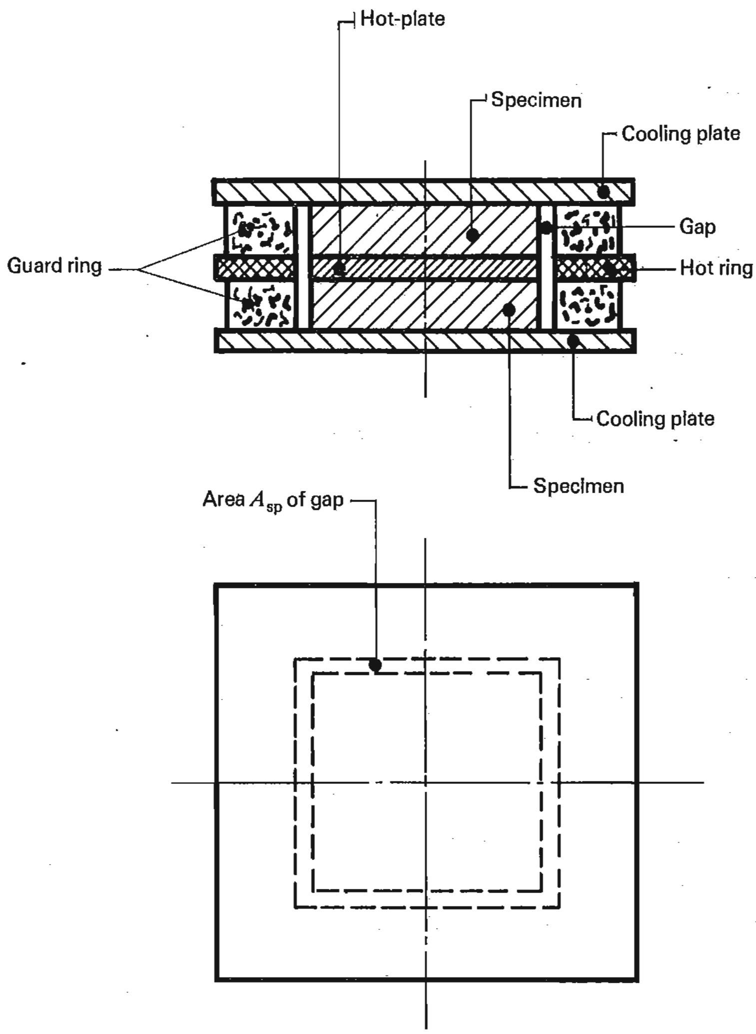

Figure 3 — Illustration of gap area (A_{sp})

11.2 Moisture content

The mass referenced moisture content, u_m, as a percentage, is given by the equation

$$u_m = \frac{m_f - m_t}{m_{tr}} \times 100 \qquad \ldots (8)$$

The volume-referenced moisture content, u_v, as a percentage, is given by the equation

$$u_v = \frac{u_m \times \varrho_R}{\varrho_W} \qquad \ldots (9)$$

where

m_f is the mass of the specimen before drying, in kilograms;

m_{tr} is the mass of the specimen after drying, in kilograms;

ϱ_R is the bulk density of the dry material, in kilograms per cubic metre;

ϱ_W is the density of water at 20 °C i.e. about 1 000 kg/m³.

12 Measurement uncertainty

The measurement uncertainty under repeat conditions when determining thermal conductivity according to this Technical Report is ± 5 %, subject to all the rules appertaining to the measuring technique being carefully observed.

13 Test report

The test report shall include the following indications:

a) reference to this Technical Report;

b) information on sampling;

c) description of the material tested;

d) test apparatus:

1) type of apparatus (single-plate, two-plate);
2) hot-plate size and shape;
3) where necessary, arrangement of the specimen in the apparatus (sketch);

e) information concerning the specimens:

1) dimensions;
2) bulk densities in the dry condition;
3) mass referred to area;
4) temperature and way of drying;
5) mean moisture content during the test;

f) measurements:

1) mean values of the test temperatures in degrees Celsius rounded to 0,1 °C;
2) mean values of the temperature differences rounded to 0,1 °C;
3) thermal conductivity to two significant figures;
4) thermal resistance rounded to two places after the decimal point.