
British Standard Methods for

Determining thermal insulating properties

Part 2. Tests for thermal conductivity and related properties

Section 2.1 Guarded hot-plate method

Méthodes de détermination des propriétés d'isolation thermique

Partie 2. Essais de la résistance thermique, de la conductivité thermique et des propriétés connexes

Section 2.1 Méthode de la plaque chauffante protégée

Verfahren zur Bestimmung der wärmedämmenden Eigenschaften

Teil 2. Prüfung des Wärmedurchlaßwiderstandes, der Wärmeleitfähigkeit und ähnlicher Eigenschaften

Abschnitt 2.1 Heizplattenverfahren

Foreword

This Section of BS 874 was prepared under the direction of the Refrigeration, Heating and Air Conditioning Standards Committee.

Previous editions of BS 874 summarized the methods available for determining thermal insulating properties, and indicated which methods were applicable to various materials intended for use in a variety of temperature ranges, but the methods themselves were not defined in detail.

The growing importance of energy conservation and the need to have reliable information about the insulating properties of materials required detailed specifications of the test methods. Accordingly, a complete revision of the standard was undertaken, with each test method being fully specified. The full revision of BS 874 will take several years to complete, and it has therefore been decided to issue each test method as a separate Section of BS 874 as and when they are completed, thus gradually replacing the 1973 edition.

This Section constitutes a revision of 4.2.1 of BS 874 : 1973 which it supersedes and which was deleted by amendment.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

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Method

0 Introduction

This Section describes an absolute guarded hot-plate method for determining the steady-state thermal transmission properties of insulating materials in the temperature range -20°C to 100°C . It is the primary method for certification and calibration work covering a wide variety of non-metallic materials and insulations in various forms.

The method is most widely used for measurements on low-density insulating materials in fibrous, cellular or granular form, although, with only slight modification to the measurement procedure, it is equally applicable to measurements on denser, more rigid materials of higher conductivity, e.g. rubber, dense plastics, glasses and masonry materials.

The standard covers guarded hot-plates of both the two-specimen symmetric and single specimen asymmetric designs in a range of sizes.

Essential design criteria, dimensions and tolerances are specified for the apparatus and minimum performance requirements are specified for the ancillary electrical and temperature measuring instruments. The measurement procedures, test conditions and specimen preparation applicable to different types of material, especially low density insulations and masonry materials, are also described in some detail. The information required in test reports is specified.

Although the precautions needed to ensure accuracy with different types of apparatus and material have been detailed in this Section, experience has shown that heat transfer measurements are far from straightforward and care should be taken to ensure that the execution of its provisions is entrusted to appropriately qualified and trained people.

This method is compatible with the corresponding method, ISO/DP 8302, being developed in the International Organization for Standardization (ISO), so that tests made in accordance with this method may be deemed to be in accordance with the ISO method. The reverse may not be true, as some of the requirements of this Section are more restrictive than those of the ISO document.

1 Scope

This Section of BS 874 describes an absolute method for determining the steady-state thermal transmission properties of insulating materials over the temperature range -20°C to 100°C using guarded hot-plate apparatus having an overall plate width or diameter greater than 300 mm and a guard width to overall plate width ratio between 1 : 4 and 1 : 6*. However, four plate widths or diameters, i.e. 305 mm, 500 mm, 610 mm and 1 m, are strongly recommended and this Section details the use of these four sizes. If it is necessary to use a hot-plate of another size, then the specimen size and other related parameters will have to be modified proportionately.

* See 6.1 for exceptions.

The method covers the measurement of the steady-state thermal resistance, conductance, conductivity and resistivity of insulating materials in fibrous, cellular, compact granular or solid form over the following ranges:

- (a) thermal resistance, R , $> 0.02 \text{ m}^2 \cdot \text{K/W}$;
- (b) thermal conductance, $C = 1/R$, $< 50 \text{ W}/(\text{m}^2 \cdot \text{K})$;
- (c) thermal conductivity, λ , $< 2 \text{ W}/(\text{m} \cdot \text{K})$;
- (d) thermal resistivity, $r = 1/\lambda$, $> 0.5 \text{ m} \cdot \text{K/W}$.

NOTE 1. It is recommended that this Section be read in conjunction with BS 874 : Part 1.

NOTE 2. The titles of the publications referred to in this standard are listed on the inside back cover.

2 Definitions

For the purposes of this Section of BS 874, the definitions given in BS 874 : Part 1 apply.

3 Restrictions on the determination of thermal conductivity and resistivity

3.1 General

Materials tested by this method may be divided into three categories as follows:

- (a) homogeneous isotropic materials through which heat is transmitted by solid conduction only, e.g. dense plastics, rubbers and pyrex glass;
- (b) thermally homogeneous porous materials through which heat may be transmitted by a combination of solid and gaseous conduction and radiation, e.g. fibrous, cellular and granular insulations and aerated concretes;
- (c) thermally inhomogeneous materials through which heat may be transmitted by conduction or a combination of processes as in (b), i.e. miscellaneous insulation materials or systems having layered or other structures causing non-uniform heat transfer through them.

NOTE. Thermally homogeneous materials in the context of this Section are materials whose measured thermal conductivity or resistivity, at any given temperature, is not affected by a change in the temperature gradient, or the thickness or area of the test specimens. Materials which contain a random distribution of inclusions or cavities whose dimensions are small relative to the specimen thickness are regarded as homogeneous but layered structures that appreciably distort the heat flux distribution are not.

Thermal conductivity and resistivity may be regarded as intrinsic properties of materials falling within category (a) and no restrictions apply to their determination by this method.

Thermal conductivity and resistivity are not intrinsic properties of materials in category (b), but, provided that these materials are thermally homogeneous, the concept of an effective thermal conductivity, or resistivity may be employed to describe their thermal behaviour for engineering design and similar purposes. If preferred, however, their behaviour may equally be described in terms of the resistance or conductance of test specimens under the particular conditions of test employed.

The behaviour of thermally inhomogeneous materials in category (c) may under no circumstances be described in terms of a thermal conductivity or resistivity and only the thermal resistance or conductance of the specimens under the conditions of test, i.e. at a particular specimen thickness, temperature difference and plate emissivity, may be referred to.

3.2 Low density materials

Special precautions, involving tests at several different thicknesses within the permissible range of the apparatus, are required to determine whether an effective thermal conductivity or resistivity can be assigned to very low density insulating materials in which radiation is a significant mode of heat transfer. As the radiation absorption coefficient in such materials is always smaller in their surface layers than within their bulk, it follows that the measured thermal conductivity value will vary with the thickness of the test specimens used, tending to be low at small specimen thicknesses and to approach a constant value as the thickness is increased. This effect increases as the optical density of the material under test decreases. When an effective thermal conductivity value is required for a material of this type, two conditions have to be satisfied:

- (a) the reported value has to be representative of the material at very large thicknesses, i.e. independent of the thickness effect described above to within 2 %; and
- (b) the in-service thickness of the material has to be large enough for the thickness effect to be negligible in the context of its overall thermal behaviour.

To check that these conditions are met several measurements at constant mean temperature and constant temperature difference, representative of service conditions, are required using specimens of different thicknesses within the allowable range of the apparatus, so that a graph of the thermal resistance R versus the specimen thickness d at a given density can be plotted for the material. Provided the specimens are not too thin, the points will fall on a straight line with a positive slope and a positive intercept R_i on the R axis at zero thickness. The effective thermal conductivity of the material at very large thicknesses can then be determined from the slope of the graph, given by

$$\lambda = \frac{\Delta d}{\Delta R} = \frac{d}{R - R_i}$$

Whether this value accurately represents the thermal behaviour of the material at its in-service thickness d_s can be ascertained by comparing the values of d_s/R_s and $d_s/(R_s - R_i)$. If the difference between these two values is less than 2 %, then an effective thermal conductivity, or resistivity can be assigned to the material. If the intercept R_i is sufficiently small for a particular product it will be possible to determine its effective thermal conductivity from a single test measurement at a convenient specimen thickness in the same way as for more dense materials, but to validate this procedure for a particular product it has to be shown that, for the specimen thickness used,

d/R and $d/(R - R_i)$ differ by less than 2 %. The thermal behaviour of materials complying with these conditions may equally be described in terms of their thermal resistance, or conductance at their in-service thickness, if preferred. If the thickness-dependence of the thermal conductivity value remains significant beyond the product's in-service thickness, then its behaviour may be described only in terms of its thermal resistance determined either by measurement under a declared set of conditions (temperature difference, etc.) using specimens having the in-service thickness and density, or, if the in-service thickness of the material is greater than the maximum allowable specimen thickness for the apparatus, by interpolation using the linear relationship between R and d , described above. If the thickness effect is significant at the in-service thickness, this shall be noted in the test report. Similar non-linear effects in other types of composite material associated, for example, with inadequate homogeneity shall also be noted in the test report and allowed for either by appropriately increasing the declared uncertainty of the measurement or by referring in the test report to a thermal resistance measurement at a given specimen thickness.

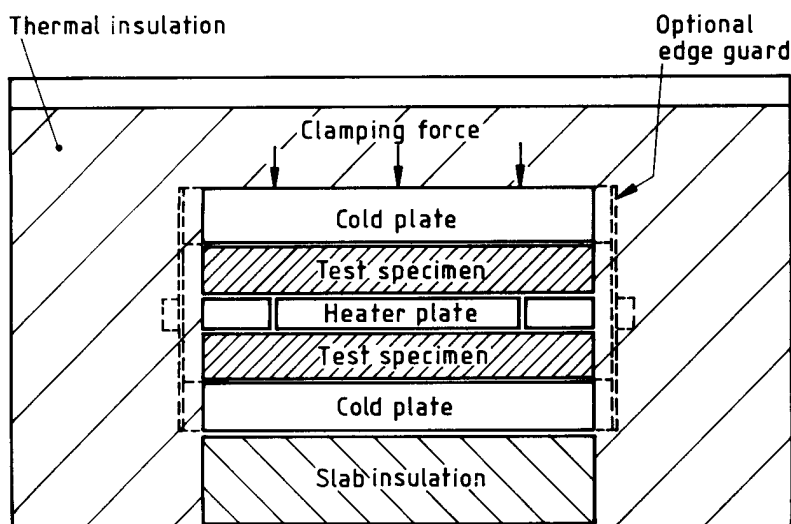
4 Principle

4.1 General

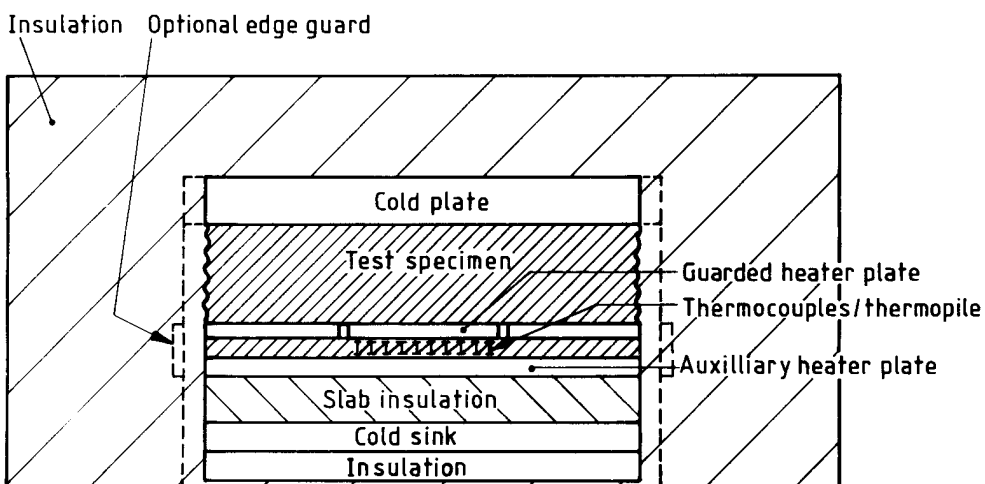
The determination of thermal conductivity and related properties by this method involves the measurement of the average temperature gradient produced through the thickness of the test specimens by a known unidirectional heat flux density under steady-state conditions.

Unidirectional heat transmission is closely approximated in the apparatus through the use of a guarded heater plate designed to produce, in specimens of limited dimensions, the steady-state thermal behaviour of an infinite slab bounded by two parallel isothermal planes. The heater plate comprises two independently heated sections, a central measuring section and a surrounding guard separated from it by an air gap some 1.5 mm to 2 mm wide. When thermocouples, or a thermopile, set in the plates on either side of this gap, indicate that the two sections are at exactly the same temperature, then unidirectional heat flow can be assumed to have been established in the central guarded region, provided that the specimen thickness is within the maximum permissible value for the apparatus; this being determined by the overall size of the apparatus and the width of its guard section.

Two guarded hot-plate designs are specified and these are illustrated schematically in figures 1(a) and 1(b). The basic two-specimen symmetric design shown in figure 1(a) is preferred for smaller apparatus, i.e. up to the 500 mm size, whilst the single-specimen asymmetric variant shown in figure 1(b), in which the guarded heater plate is supported on a rigid base, is more practicable for the larger units needed for measurements on low-density insulation at thicknesses greater than 100 mm.



(a) Two-specimen symmetric guarded hot-plate apparatus



(b) Single-specimen asymmetric, guarded hot-plate apparatus

Figure 1. Guarded hot-plate apparatus