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Metallic and other inorganic coatings — Determination of thermal conductivity of thermal barrier coatings

Revêtements métalliques et autres revêtements inorganiques — Détermination de la conductivité thermique des revêtements barrières thermiques

Reference number
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Foreword

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 107, *Metallic and other inorganic coatings*.

Introduction

Thermal barrier coatings are highly advanced material systems. They are generally applied to surfaces of hot-section components made of nickel or cobalt-based superalloys, such as combustors, blades, vanes of power-generation gas turbines in thermal power plants and aero-engines operated at elevated temperatures.

The function of these coatings is to protect metallic components for extended periods at elevated temperatures by employing thermally insulating materials which can sustain an appreciable temperature difference between load bearing alloys and coating surfaces. These coatings permit the high-temperature operation by shielding these components, thereby extending their lives.

Although thermal conductivity is one of the most important properties of thermal barrier coatings, the existing International Standard (ISO 18755:2005) includes only the method for determining the thermal diffusivity of monolithic ceramics, regarding the heat conduction in thermal barrier coating.

Metallic and other inorganic coatings — Determination of thermal conductivity of thermal barrier coatings

1 Scope

This International Standard specifies the method for determining the thermal conductivities of thermal barrier coatings consisting of metallic bond coats and ceramic top coats, in a direction normal to the coating surface, at room temperature.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 1463, *Metallic and oxide coatings — Measurement of coating thickness — Microscopical method*

ISO 18755:2005, *Fine ceramics (advanced ceramics, advanced technical ceramics) — Determination of thermal diffusivity of monolithic ceramics by laser flash method*

EN 821-3, *Advanced technical ceramics — Monolithic ceramics. Thermophysical properties — Part 3: Determination of specific heat capacity*

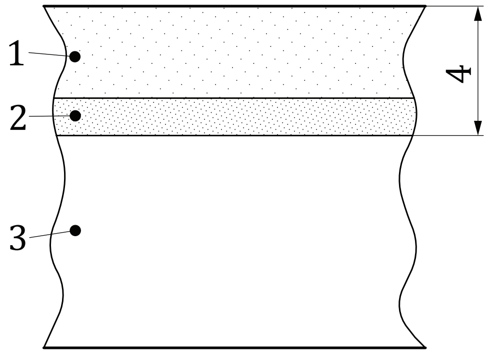
ASTM E1269-11, *Standard Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry*

3 Terms and definitions

For the purpose of this standard, the terms and definitions given in ISO 18755:2005 and the following apply.

3.1
thermal barrier coating
TBC
two-layer coating consisting of a metallic bond coat (BC) and a ceramic top coat (TC), in order to reduce heat transfer from outside of the top coat through the coating to the substrate

Note 1 to entry: See Figure 1.



Key

1 top coat (TC)

2 bond coat (BC)

3 substrate

4 thermal barrier coating (TBC)

Figure 1 — Diagrammatic view of a section of TBC

[SOURCE: ISO 14188:2012, definition 3.1, modified]

3.2
apparent thermal diffusivity
thermal diffusivity of the specimens [substrate with bond coat (BC) and substrate with thermal barrier coating (TBC)] in a direction normal to the coating surface

3.3
normalized temperature rise
T*(*t*)/Δ*T
value which is determined by dividing the difference between the temperature of the specimen rear surface after the pulse heating and the temperature of the specimen rear surface before the pulse heating by the difference between the maximum temperature of the specimen rear surface and the temperature of the specimen rear surface before the pulse heating

$$\frac{T(t)}{\Delta T} = \frac{T_1(t) - T_0}{T_{max} - T_0}$$

where

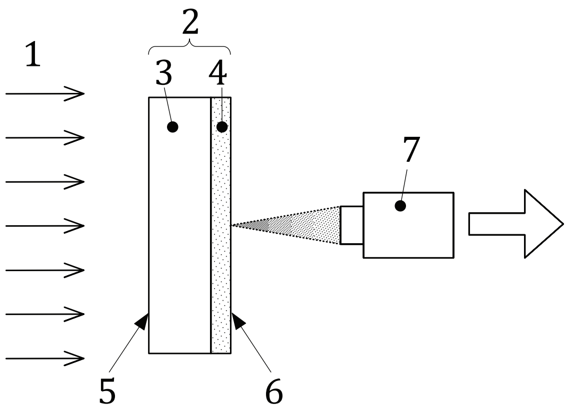
$T_1(t)$ is temperature of specimen rear surface after pulse heating by a flash method;

t is time;

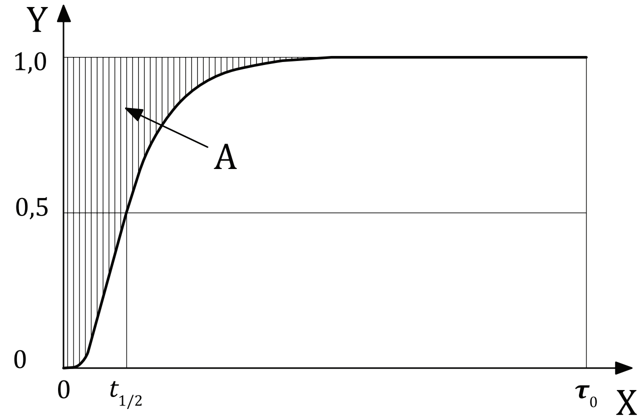
T_0 is temperature of the specimen rear surface before pulse heating;

T_{max} is maximum temperature of specimen rear surface.

Note 1 to entry: See Figure 2.



a) Flash method



b) Temperature-rise curve under ideal conditions

Key

1 pulse heating
2 specimen
3 substrate
4 TBC
5 front surface
6 rear surface
7 infrared radiometer

X time (s)
Y normalized temperature rise $T(t)$ / ΔT
A areal heat diffusion time (s)

Figure 2 — Flash method and temperature-rise curve under ideal conditions

3.4
temperature-rise curve
curve which shows the variation in the normalized temperature rise of the specimen rear surface with time

Note 1 to entry: See the thick solid line in Figure 2b.

3.5
half rise-time
$t_{1/2}$
time required for the normalized temperature rise to reach 0,5 in the temperature-rise curve

Note 1 to entry: See Figure 2b.

3.6
areal heat diffusion time
A
area with time-dimension which is bordered by the horizontal line at the height of the maximum temperature-rise and by the temperature-rise curve

Note 1 to entry: See Figure 2b.

3.7
heat diffusion time
τ_0
time period beginning with pulse heating of the specimen front surface until time at which the specimen temperature becomes uniform

$$\tau_0 = \frac{d^2}{\alpha}$$

where

τ_0 is heat diffusion time (s);

d is thickness of specimen (m);

α is thermal diffusivity (m^2/s).

Note 1 to entry: See Figure 2b.

4 Principle

Thermal conductivities of the substrate, BC, and TC are determined according to calculations using the thermal diffusivities, specific heat capacities and bulk densities. The fundamental procedures are shown in Figure 3.

The fundamental procedures for determining the thermal diffusivities of the substrate, BC, and TC consist of the measurement of temperature-rise curves of three types of specimens (substrate, substrate with BC, and substrate with TBC) by a flash method, and of calculations. The thermal diffusivities of the BC and TC are obtained by applying a multi-layer analytical model to the temperature-rise curves.

The specific heat capacities and bulk densities of the substrate, BC, and TC are measured separately.

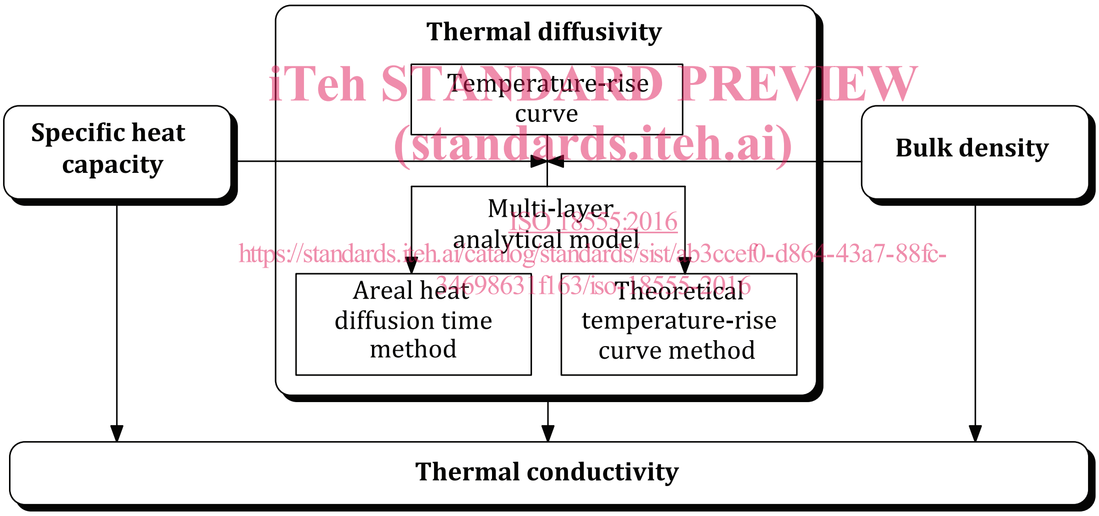


Figure 3 — Fundamental procedures for determining thermal conductivity

5 Apparatus for measuring thermal diffusivity

An example of the apparatus for measuring the thermal diffusivity is schematically shown in Figure 4.

The apparatus consists of the following.

5.1 Pulse heating light source.

5.2 Data recorder.

5.3 Measurement circuit.

5.4 Infrared radiometer.

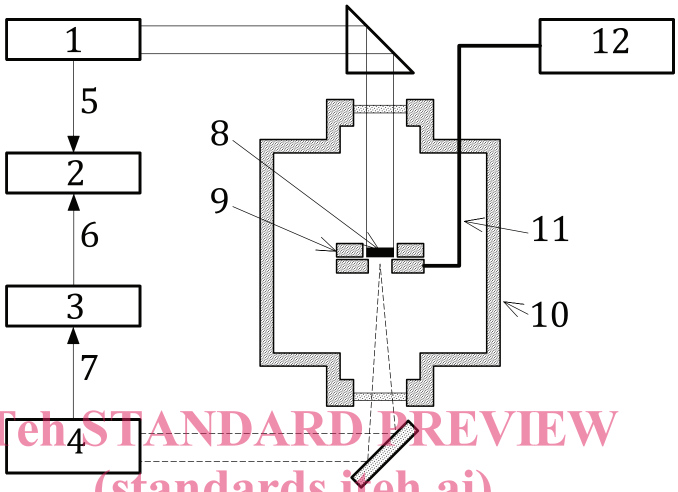
5.5 Specimen holder.

5.6 Chamber.

5.7 Thermocouple.

5.8 Temperature indicator.

The apparatus shall be specified according to ISO 18755:2005 and should be calibrated using reference data and reference materials in reference to Annex E in ISO 18755:2005.



Key

1 pulse heating light source
2 data recorder
3 measurement circuit
4 infrared radiometer
5 trigger signal
6 amplification of signal
7 temperature signal of specimen rear surface
8 specimen
9 specimen holder
10 chamber
11 thermocouple
12 temperature indicator

Figure 4 — Typical apparatus for measuring the thermal diffusivity according to a flash method

6 Specimen

6.1 Shape and dimensions

The shape and dimensions of the specimen shall be as follows.

a) The three types of specimens (the substrate, BC and TBC specimens) shall be used.

b) The specimen shape shall be a flat disk (Figure 5) or flat square plate (Figure 6). The diameter or side length of the specimen shall be from 10×10^{-3} m to 15×10^{-3} m.

c) The thicknesses of the substrate, BC and TC are given in Table 1.

d) The substrate thickness shall be the same for the three types of specimens.

e) The thickness tolerance of substrate shall be $\pm$ 0,01 $\times 10^{-3}$ m.

f) The thickness of BC shall be the same for the BC and TBC specimens.