INTERNATIONAL STANDARD

ISO 16378

Second edition
2022-09

Space systems — Measurements of thermo-optical properties of thermal control materials

Systèmes spatiaux — Mesures des propriétés thermo-optiques des matériaux de thermorégulation

Reference number
ISO 16378:2022(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This second edition cancels and replaces the first edition (ISO 16378:2013), which has been technically revised.

The main changes are as follows:

— updated terms and definitions according to the referenced document revision;

— revised description of sample thickness precision requirements;

— deleted solar absorptance measurement with central sample mounting sphere.

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.

Introduction

Solar absorptance and infrared emittance are the key parameters of materials for both active and passive thermal design of space systems.

This document describes the methodology, instruments, equipment, and samples used to calculate the key parameters of thermal-control materials, i.e. solar absorptance (α_s or α_p) and the infrared emittance (ε_h or ε_n). The measurements defined in this document are performed at ground test facilities with the purpose of obtaining material properties. The measured properties are used for material selection, thermal design of spacecraft, process control, quality control, etc. Also, on-orbit temperature data in the beginning of life can be assessed using the data obtained by ground measurement.

Space systems — Measurements of thermo-optical properties of thermal control materials

1 Scope

This document specifies the multiple measurement methods, instruments, equipment, and samples used to calculate the thermo-optical properties of thermal control materials. This document compares their features, indicates their limitations and biases, and guides the applications. This document also defines requirements for calibration and reference materials to ensure data quality.

This document specifies the following test methods, including the configuration of samples and calculations.

a) Solar absorptance using a spectrophotometer (α_s) — Annex A.

b) Solar absorptance using the comparative test method (α_p) — Annex B.

c) Hemispherical infrared emittance using the thermal test method ($\varepsilon_{h\text{-}t}$) — Annex C.

d) Normal infrared emittance using an IR spectrometer ($\varepsilon_{n\text{-}s}$) — Annex D.

e) Normal infrared emittance using ellipsoid collector optics ($\varepsilon_{n\text{-}e}$) — Annex E.

f) Normal infrared emittance using two rotating cavities ($\varepsilon_{n\text{-}c}$) — Annex F.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
absorptance
α
quotient of absorbed *radiant flux* (3.8) and incident radiant flux, expressed by

$$\alpha = \Phi_a/\Phi_m$$

where Φ_a is absorbed radiant flux and Φ_m is incident radiant flux

[SOURCE: ISO 80000-7:2019, 7-31.1]

3.2
emittance
ε
quotient of the radiant exitance of a radiator and the radiant exitance of a Planckian radiator at the same temperature, expressed by

$$\varepsilon = M/M_\mathrm{b}$$

where M is the radiant exitance of a thermal radiator and M_b is the radiant exitance of a Planckian radiator at the same temperature

EXAMPLE Total hemispherical emittance.

Note 1 to entry: Total hemispherical exitance M of the considered surface divided by the total hemispherical exitance M_0 of the blackbody at the same temperature (see ISO 9288).

Note 2 to entry: The following adjectives should be added to define the conditions.

— Total: If they are related to the entire spectrum of thermal radiation (this designation can be considered as implicit) (see ISO 9288).

— Spectral or monochromatic: If they are related to a spectral interval centred on the wavelength λ (see ISO 9288).

— Hemispherical: If they are related to all directions along which a surface element can emit or receive radiation (see ISO 9288).

— Directional: If they are related to the directions of propagation defined by a solid angle around the defined direction (see ISO 9288).

— Normal: If they are related to the normal direction of propagation or incidence to the surface.

Note 3 to entry: When there is a certain need to distinguish a property of a material from a property of a real object, the word "emissivity" can be used. Emissivity is a property of a material defined in terms of the emittance of an ideal material that is semi-infinite medium limited by optically smooth surface. Annex H provides further information about theoretical emissivity and practical emittance.

Emissivity depends on the temperature at which it is determined and wavelength range.

Emittance is a property of a particular object. It is determined by material emissivity, surface roughness, oxidation, the sample's thermal and mechanical history, surface finish, and measured wavelength range. Although emissivity is a major component in determining emittance, the emissivity determined under laboratory conditions seldom agrees with actual emittance of a certain sample.

$$\varepsilon = \int_0^\infty L_b(\lambda,T)\varepsilon\ (\lambda)d\lambda \Big/ \int_0^\infty L_b(\lambda,T)d\lambda$$

where

$L_b(\lambda,T)$	is the spectral Planck distribution of blackbody radiation, $C_1\lambda^{-5}\left(\mathrm{e}^{C_2/\lambda T}-1\right)^{-1}$;
C_1	is 3,741 77 × 10^{-16} W·m^2;
C_2	is 1,438 8 × 10^{-2} m·K;
T	is the absolute temperature, K;
λ	is the wavelength, m;
$\int_0^\infty L_b(\lambda,T)d\lambda$	$\sigma\pi^{-1}T^4$;

σ is the Stefan-Boltzmann constant, 5,670 400 (40) × 10^{-8} W·m^{-2}·K^{-4}.

[SOURCE: ISO 80000-7:2019, 7-30.1, modified — The term has been changed to "emittance"; the EXAMPLE and notes to entry have been added.]

3.3
diffuse
indicating that flux propagates in many directions, as opposed to direct beam, which refers to a collimated flux

Note 1 to entry: When referring to *reflectance* (3.9), diffuse reflectance is the ratio of the diffusely reflected part of the (whole) reflected flux to the incident flux.

3.4
infrared emittance
emittance (3.2) in the infrared range at least from 5 µm to 25 µm

3.5
integrating sphere
optical device, which is used to either get flux proportional to that reflected or transmitted from a sample into a hemisphere or to provide uniform irradiation of a sample from the whole hemisphere

Note 1 to entry: It consists of a cavity with apertures for admitting and detecting flux and usually having additional apertures over which sample and reference specimens are placed.

3.6
irradiance
E_e
density of incident *radiant flux* (3.8) with respect to area at a point on a real or imaginary surface, expressed by

$$E_e = d\Phi_e/dA$$

where Φ_e is radiant flux and A is area (see ISO 80000-3) on which the radiant flux is incident

Note 1 to entry: It is expressed in W/m^2.

[SOURCE: ISO 80000-7:2019, 7-7.1, modified — Note 1 to entry has been added.]

3.7
near-normal-hemispherical
indicating *irradiance* (3.6) to be directional near-normal to the specimen surface and that the flux leaving the surface or medium is collected over an entire hemisphere for detection

3.8
radiant flux
Φ_e
change in radiant energy with time, expressed by

$$\Phi_e = dQ_e/dt$$

where Q_e is the radiant energy emitted, transferred, or received and t is time(ISO 80000-3)

Note 1 to entry: It is expressed in W.

[SOURCE: ISO 80000-7:2019, 7-4.1, modified — The alternative term "radiant power" has been removed; note 1 to entry has been added.]

3.9
reflectance
ρ
quotient of reflected *radiant flux* (3.8) and incident radiant flux, expressed by

$$\rho = \Phi_r / \Phi_m$$

where Φ_r is reflected radiant flux and Φ_m is incident radiant flux

[SOURCE: ISO 80000-7:2019, 7-31.3]

3.10
solar
<radiometric> indicating that the radiant flux involved has the Sun as its source or has the relative spectral distribution of solar flux

Note 1 to entry: The adjective "solar" is used for optical field as indicating a weighted average of the spectral property, with a standard solar spectral *irradiance* (3.6) distribution as the weighting function.

3.12
solar absorptance
α_s
ratio of the *solar* (3.10) *radiant flux* (3.8) absorbed by a material (or body) to the radiant flux of the incident radiation

Note 1 to entry: Differentiation is made between two methods:

a) Method of spectral measurements using a spectrophotometer covering the range from 250 nm to 2 500 nm for the determination of α_s. In this case a weighted mean value of spectral characteristics with standard spectral distribution of solar irradiation as a weighting function is calculated.

b) Method of α_p measurements using the tools which measure integral reflection factor by using a comparison method. In this case a portable equipment is used which has a source of irradiation with spectral distribution near to solar spectral distribution or when the registration is performed by using spectral correcting elements, which can simulate registration of solar irradiation flux.

3.13
solar irradiance
radiation of the Sun integrated over the full disk and expressed in SI units of power through a unit of area, $W \cdot m^{-2}$

[SOURCE: ISO 21348:2007, 7-4.1, modified — Note 1 to entry has been removed.]

3.14
spectral
indicating that the property was evaluated at a specific wavelength, λ, within a small wavelength interval, $\Delta\lambda$ about λ

Note 1 to entry: The parameters of frequency, ν, wave number, κ, or photon energy can be substituted for wavelength, λ, in this definition.

Note 2 to entry: At a specific wavelength, the wavelength at which the spectral concentration was evaluated can be indicated by the wavelength in parentheses following the symbol, such as α_s(350 nm), or as a function of the wavelength, such as $\alpha_s(\lambda)$.

3.16
specular
indicating that the flux leaves a surface or medium at an angle that is numerically equal to the angle of incidence, lies in the same plane as the incident ray and the perpendicular, but is on the opposite side of the perpendicular to the surface

Note 1 to entry: Reversing the order of terms in an adjective reverses the geometry of the incident and collected flux, respectively.

3.17
transmittance
τ
quotient of transmitted *radiant flux* (3.8) and incident radiant flux, expressed by

$$\tau = \Phi_t / \Phi_m$$

where Φ_t is transmitted radiant flux and Φ_m is incident radiant flux

[SOURCE: ISO 80000-7:2019, 7-31.5]

4 Abbreviated terms

IR infra-red

RT room temperature

5 Preparatory conditions

5.1 Hazards, health, and safety precautions

Attention shall be given to health and safety precautions. Hazards to personnel, equipment, and materials shall be controlled and minimized.

5.2 Preparation of samples

5.2.1 Sample property

This document is applicable to materials having both specular and diffuse optical properties.

5.2.2 Configuration

The material samples shall be prepared according to the relevant process specification or manufacturer's data and shall be representative of batch variance.

The samples shall represent the work piece as exactly as possible. Expected changes in thermo-optical properties from the measured sample to the flight equipment shall be considered in thermal design.

For instance, the application procedure for paint can result in different thermo-optical properties depending on the painter and the type of spray gun used; therefore, the samples should be coated or made at the same time as the work piece.

The surface roughness strongly affects the measurement results. Bare (uncoated) samples shall be finished to the same surface condition as the work piece.

5.2.3 Cleaning

The cleaning method and other treatment of the sample shall always be the same as for the flight hardware. Further cleaning or treatment of the sample is not allowed.

In particular, solar absorptance properties are very sensitive to contamination and if the sample or the flight hardware is contaminated (even by hand grease), the test results can be significantly in error.

5.2.4 Handling and storage

Samples shall only be handled with clean nylon or lint-free gloves and shall be stored in a cleanliness-controlled area, with a room temperature of 15 °C to 30 °C and a relative humidity of 20 % to 65 %.

Care should be taken to prevent excessive change from storage condition to measurement condition.

a) Coated surfaces shall be shielded from contact by using soft and inert material such as polyethylene or polypropylene bags or sheets.

b) Mechanical damage shall be avoided in the standard way by packing the wrapped samples in clean and dust and lint-free material.

c) Limited-life materials shall be labelled with their relative shelf lives and dates of manufacture.

5.2.5 Identification

a) Samples submitted for testing shall be accompanied by a completed “Material identification card”.

b) Hazardous samples shall be accompanied by a completed “Safety data sheet”.

c) The surface of the samples which is to be measured shall be clearly indicated unless the samples have completely even properties on both surfaces.

5.3 Facilities

5.3.1 Cleanliness

a) The work area shall be clean and free of dust.

b) Air used for ventilation should be filtered to prevent contamination of the sample.

5.3.2 Environmental conditions

The ambient conditions for the process and work areas shall be from 15 °C to 30 °C with a relative humidity of 20 % to 65 % unless otherwise stated.

5.3.3 Equipment

The equipment is specific for each test and defined in the Annexes.

5.4 Standard materials

5.4.1 General

Both reference and working (comparison) standards are required. Highly durable materials are preferred. Standard materials shall be handled and stored in accordance with the associated specification. Avoid touching the optical surfaces even with gloves.

5.4.2 Reference standard material

Reference standards are the primary standard material for the calibration of instruments and working standards. Reference standards shall be traceable to a national or an international authority having jurisdiction.

5.4.3 Working standard material

Working standards are used in the daily operation of the instrument to provide comparison curves for data reduction. A working standard shall be calibrated annually by measuring its thermo-optical properties relative to the properties of the appropriate reference standard. If degradation is noticeable, the working standard shall be cleaned, renewed or replaced.

5.4.4 Solar absorptance

For transmitting samples, incident radiation shall be used as the standard relative to which the transmitted light is evaluated. For some applications, calibrated transmittance standards are available.

For diffuse high-reflectance samples, a working standard that has high reflectance and is highly diffusing over the range of the solar spectrum is required.

NOTE 1 White diffuser is commonly used as a diffuse high-reflectance standard material. Various white diffusers are provided by a national or an international authority such as NIST. Spectralon®[1)] is a commercially available material that provides high-diffuse reflectance for 250 nm to 2 500 nm. $BaSO_4$ and magnesium oxide have been widely utilized but are no longer recommended for use as a standard since they are not stable for longer periods.

For specularly reflecting samples, a working standard that is highly specular is required. Identified suitable working standards are vacuum-deposited thin opaque films of metals. All front surface metalized working standards shall be calibrated frequently with an absolute reflectometer or relative to a national or an international standard reference material before being acceptable in this test method.

NOTE 2 Aluminium-coated glass mirror is widely used because of its high reflectance and ease of deposition. Although bare aluminium surface is highly vulnerable, protective coating can maintain the optical property.

For absorber materials, a working standard that has low reflectance over the range of the solar spectrum is required in order to obtain an accurate zero line correction.

5.4.5 Infrared emittance

A set of high- and low-emittance materials are often provided by the instrument manufacturer as standard materials. Typical high- and low-emittance standards can consist of black paint (or preferably a blackbody cavity) and polished high-purity aluminium, respectively.

6 Solar absorptance (α_s) test methods

Two test methods are described in this clause.

Though α_p has slightly bigger standard deviations than α_s, both methods provide well-repeatable data to use in thermal design. Solar absorptance obtained by these two methods shall be clearly distinguished by the terms α_s and α_p.

a) Solar absorptance using a spectrophotometer (α_s)

---

1) Spectralon® is the trademark of a product supplied by Labsphere. This information is given for the convenience of users of this document and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

